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FRACTIONAL EFFICIENCY OF A UTILITY BOILER BAGHOUSE

SUNBURY STEAM-ELECTRIC STATION

GCA CORPORATION

PREPARED FOR
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FRACTIONAL EFFICIENCY OF A UTILITY BOILER BAGHOUSE:
Sunbury Steam-Electric Station

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FRACTIONAL EFFICIENCY
OF A UTILITY BOILER BAGHOUSE:
SUNBURY STEAM-ELECTRIC STATION

by

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16. ABSTRACT The report gives results of extensive tests of a fabric filter baghouse operating on the effluent of a coal-fired utility boiler burning a mixture of petroleum coke and anthracite silt. The tests were conducted to determine the total mass and fractional efficiencies of the baghouse during normal and abnormal operation with brand new and used filter bags. Total mass samplers, inertial impactors, and a condensation nuclei counter were used to sample the baghouse influent and effluent. Results of the normal tests with the brand new and used bags determined the baghouse mean mass removal efficiencies to be 99.88 and 99.93%, respectively. Statistical analysis of the test results showed that the purposely altered variables had no significant effect on either the outlet concentration or penetration for normal and abnormal tests of the used bags. However, there were significant differences in the outlet concentrations and penetrations when the normal tests were compared for the new and used bags. There were also significant differences in the outlet concentrations when the new bag normal and abnormal tests were compared.

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Dust Control	Combustion	Stationary Sources	05E	21B
Dust Collectors	Coal	Sunbury Plant	13A	21D
Fabrics	Petroleum Coke	Particulate	11E	
Filtration	Anthracite	Baghouse	07D	
Tests	Silts	Fabric Filters	14B	
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The GCA Project Administrator was Mr. Norman Surprenant.

CONVERSION FACTORS FOR BRITISH AND METRIC UNITS

To convert from	To	Multiply by	To	Multiply by
^{o}F	^{o}C	$\frac{5}{9}$ ($^{o}F-32$)	—	—
ft.	meters	0.305	centimeters	30.5
ft.^{2}	meters^2	0.0929	centimeters^2	929.0
ft.^{3}	meters^3	0.0283	centimeters^3	28,300.0
ft./min. (fpm)	centimeters/sec.	0.508	meters/sec.	5.08×10^{-3}
ft.^{3}/min.	centimeters^3/sec.	471.9	meters^3/hr.	1.70
in.	centimeters	2.54	meters	2.54×10^{-2}
in.^{2}	centimeters^2	6.45	meters^2	6.45×10^{-4}
oz.	grams	28.34	grains	438.0
oz./yd.^{2}	grams/meter^2	33.89	grams/centimeter^2	3.39×10^{-3}
grains	grams	0.0647	—	—
grains/ft.^{2}	grams meter^2	0.698	—	—
grains/ft.^{3}	grams/meter^3	2.288	—	—
lb. force	dynes	4.44×10^5	Newtons	0.44
lb. mass	kilograms	0.454	grams	454.0
lb./ft.^{2}	grams/centimeter^2	0.488	grams/meter^2	4,880.0
in. H_2O/ft./min.	cm. H_2O/cm/sec.	5.00	Newtons/meter^2/cm/sec.	490.0
Btu	calories	252	—	—

SECTION I

CONCLUSIONS

The test results show that a fabric filter installed on a boiler burning anthracite silt and petroleum coke is an effective means of controlling particulate emissions. The mean emission rates for the normal total mass tests with the new and used bags were 0.0058 and 0.0045 pounds per million Btu, respectively. These emission rates are well within Pennsylvania's maximum of 0.105 pounds per million Btu.

The baghouse operated for 2 years with the original bags with only slight problems and without appreciable bag failures. The characterization tests (physical properties) performed on samples of the 2-year-old fabric and new fabric found the used fabric to be nearly as strong as the new. At the end of 2 years, the pressure drop across the baghouse at full load was a nearly constant 2.5 in. H_2O which was well within the maximum allowable pressure drop of 5.0 in. H_2O.

Statistical analysis of the results of the used bags tests showed that the purposely altered operating parameters listed below had no significant effect on either the particle penetration through the baghouse or the outlet mass concentration. However, significant differences in the penetration and outlet concentration were found when the results of the normal tests with the used bags and new bags were compared. Also, there were significant differences in the outlet concentrations when the normal new bag tests were compared with the abnormal new bag tests. The purposely altered operating parameters included:

- The ash and sulfur content of the coal
- The boiler steam flow
- The number of compartments in service
- The time interval between cleaning cycles.

A multiple regression analysis of the test results indicated that the particulate penetration through the baghouse and the outlet mass concentration for the grouped results of normal tests with the new bags and for the grouped results of all the tests were most dependent upon the inlet mass concentration and the pressure drop across the baghouse. However, the penetration and outlet concentration for the grouped results of normal tests with the used bags were indicated to be most dependent upon the moisture content of the fuel and the baghouse face velocity.

SECTION II

RECOMMENDATIONS

It is recommended that extreme caution be exercised when sampling a source with a high SO_3 concentration with an Andersen impactor using glass substrates. When sampling an effluent with a high SO_3 concentration, preliminary measurements should be made to determine if an anomalous weight gain problem exists and what modifications need to be made to compensate for the problem. Also, when sampling with an impactor, an effort should be made to eliminate sampling through a gooseneck nozzle because of the significant losses in the probe. In addition, the Andersen cyclone precollector should only be used when the size cutoffs of the Andersen impactor's top two or three stages are not of interest because the cyclone collects significant amounts of particles which would impact on these stages. Also, there is a need for a combination of impactors to be used when performing a fractional efficiency type of evaluation on a control device which would allow simultaneous influent and effluent sampling and thereby reduce the effects of temporal variations.

More work needs to be done in three basic areas to perfect a submicron particle counting and sizing technique using the condensation nuclei counter (CNC) and diffusion denuder (DD). First, the condensation nuclei counter needs to be redesigned for field use to eliminate sensitivity due to variations in temperature and static pressure. Second, the problems of conditioning the sample to provide a sample to the CNC which is representative of what is within the stack need more consideration. It is felt that effecting a dilution in the stack is the best way to obtain a representative sample. Third, an accurate method to verify the CNC field measurements needs to be developed.

SECTION III

INTRODUCTION

BACKGROUND

The work reported in this publication represents one phase of a program whose purpose is to characterize the performance of several industrial size fabric filter systems. Although fabric filtration technology has been successfully applied to a wide variety of industrial processes, there are several areas where baghouse filters have not been or are just beginning to be utilized.

One of the recent applications is that for the control of particulate emissions from coal-fired utility boilers. The potential for the use of baghouses on boiler flue gases is very large. Only recently, however, has the successful application in this area, which represents a significant advancement in the state-of-the-art, been demonstrated.

APPROACH

The performance of a fabric filter was characterized by determination of the particulate removal efficiency as a function of total mass and particle size. The total mass efficiency was determined by collecting mass samples before and after the baghouse. The fractional efficiency, defined as the measured change in the particulate concentration as a function of particle size that results from the filtration process, was determined by upstream and downstream sampling using inertial and diffusional sizing

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techniques. Tests were performed at several different boiler and baghouse operating conditions to determine what parameters, if any, would affect a significant difference in fabric filter performance.

The first phase of the baghouse performance characterization was to gain knowledge of the installation through a pretest survey and to use this knowledge to formulate a test plan. During the pretest survey it was learned that three types of variables could be readily changed; namely, fuel mixture, boiler load and baghouse operation. Later it was found that the baghouse was to have all its bags replaced, so this was incorporated as a test parameter.

The test plan shown in Table 1 was designed so that each series of abnormal tests was bracketed with normal tests to ascertain that measured differences were the results of controlled changes and not because of changes in normal operation. Sufficient normal tests were included in the test plan to statistically define the mean values and the range of variability occurring during normal operations. Table 2 shows the expected effects on baghouse operation made by the various changes. Although it was preferred that all the variables except those designated in the test plan should remain constant, this was not always possible. Therefore, it was necessary to obtain coal samples, plant log sheets and plant chart recordings to define the conditions for each test. Additionally, the EPA Control Systems Laboratory trailer provided instrumentation for monitoring the flue gas for sulfur dioxide, carbon monoxide, carbon dioxide and oxygen during several of the tests.

Table 1. SUNBURY TEST PLAN

Date	Run no.	Boiler load	Fuel mixture	Baghouse 1A operation	Bag age
1-8-75	1	Full[a]	Normal[b]	Normal	2 yrs
1-9-75	2	Full	Normal	Normal	2 yrs
1-10-75	3	Full	Normal	Normal	2 yrs
1-11-75	4	Full	Normal	Normal	2 yrs
1-13-75	5	Full	Max. Coke[c]	Normal	2 yrs
1-14-75	6	Full	Max. Coke	Normal	2 yrs
1-15-75	7	Full	Normal	Normal	2 yrs
1-16-75	8	Full	Min. Coke[d]	Normal	2 yrs
1-17-75	9	Full	Min. Coke	Normal	2 yrs
1-18-75	10	Full	Normal	Normal	2 yrs
2-4-75	11	Full	Normal	Normal	2 yrs
2-5-75	12	Full	Normal	Normal	2 yrs
2-6-75	13	3/4	Normal	Normal	2 yrs
2-7-75	14	3/4	Normal	Normal	2 yrs
2-8-75	15	Full	Normal	Normal	2 yrs
2-10-75	16	Full	Normal	½ hr between cleaning cycles	2 yrs
2-11-75	17	Full	Normal	½ hr between cleaning cycles	2 yrs
2-12-75	18	Full	Normal	Normal	2 yrs
2-12-75	19	Full	Normal	two (2) compartments off	2 yrs
2-13-75	20	Full	Normal	two (2) compartments off	2 yrs
2-14-75	21	Full	Normal	Normal	2 yrs
3-20-75	22	Full	Normal	Normal	1 day
3-21-75	23	Full	Normal	Normal	2 days
3-22-75	24	Full	Normal	Normal	3 days
3-23-75	25	Full	Normal	Normal	4 days
3-24-75	26	Full	Max. Coke	Normal	5 days
3-25-75	27	Full	Max. Coke	Normal	6 days
3-26-75	28	Full	Normal	Normal	7 days
3-27-75	29	Full	Min. Coke	Normal	8 days
3-28-75	30	Full	Min. Coke	Normal	9 days
3-29-75	31	Full	Normal	Normal	10 days

[a] Full = 410,000 pounds steam/hour, 955°F, 1,350 psig.

[b] Normal = 20% Coke, 80% Anthracite mixture of No. 5 Buck with Silt.

[c] Max. Coke = 35% Coke, 65% Anthracite mixture of No. 5 Buck with Silt.

[d] Min. Coke = 15% Coke, 85% Anthracite mixture of No. 5 Buck with Silt.

Table 2. EXPECTED EFFECTS OF VARIED PARAMETERS ON THE FABRIC FILTER

Test condition	Air to cloth ratio, $acfm/ft^2$	Cleaning frequency, compartments/hr	Cloth loading, $lb/ft^2/hr$	Pressure drop, $"H_2O$
Maximum coke	NC[a]	NC	decreased	decreased
Minimum coke	NC	NC	increased	increased
3/4 load	decreased	NC	decreased	decreased
1/2 hour between cleaning cycles	NC	decreased	NC	increased
2 compartments off	increased	NC	increased	increased
New bags	NC	NC	NC	decreased

[a] NC = No change expected.

SECTION IV

SUNBURY STEAM ELECTRIC STATION

PLANT DESCRIPTION

The Sunbury Steam Electric Station of the Pennsylvania Power and Light Company is located on the west bank of the Susquehanna River in Shamokin Dam, Pennsylvania. The station capacity of approximately 402 MW[1] is generated by four steam turbines. Turbine units 1 and 2, which are rated at 87.5 MW[2] each, are supplied by four anthracite-fired Foster Wheeler boilers which were placed in commercial operation in 1949 and 1950. Each boiler is rated at 410,000 pounds steam/hour with a superheated steam outlet temperature and pressure of 955°F and 1,350 psig. The boilers burn a mixture of 15 percent to 35 percent petroleum coke with the remainder made up of anthracite silt and No. 5 buckwheat anthracite. The anthracite silt and No. 5 buckwheat are obtained from culm banks and strip mines located in Northeastern Pennsylvania. The normal fuel consumption is 41 tons/hour/unit with an exhaust gas volume of approximately 125,000 scfm per boiler. Originally, particulate was removed from the flue gas by a combination mechanical-electrostatic collector. However, the collectors were unable to remove the desired amount of particulate primarily due to the high resistivity of the low sulfur anthracite fly ash. After extensive studies of the anthracite fly ash collection problem, including the operation of a Western Precipitation pilot plant bag filter, Western Precipitation bag filters were installed on the anthracite burning boilers. Since the four baghouses are identical, only one was tested. The fabric filter selected (1A boiler) was placed in service on February 10, 1973.

The location of dust removal equipment for each boiler is shown in Figure 1. After leaving the boiler economizer, the flue gas is drawn through a regenerative air heater and mechanical dust collector by an induced draft (ID) fan. The mechanical dust collector removes about 70 percent of the particulate. Upon leaving the ID fan, the flue gas flows through horizontal and vertical ducting into the inlet manifold of the baghouse. A hopper is located at the end of the horizontal run to remove any dust which settles out of the gas stream. The flue gas in the inlet manifold flows through the compartment inlet dampers, the compartment hopper section, and finally up through the thimble plate to the bag interiors. After the flue gas passes through the filter cake and bag, it discharges from the compartment via the outlet dampers and outlet flue. From the outlet flue, the cleaned gas flows through a breeching, and then exhausts to atmosphere through a stack. The stack extends 150 feet above the boiler roof which is 150 feet above grade.

BAGHOUSE DESCRIPTION

The Western Precipitation design conditions for the bag filters are presented in Table 3. The total cost of the installation of the four bag filters including the needed additional ash slurry handling system was approximately $5.5 million with the baghouses themselves accounting for about 60 percent of the total cost. A detailed breakdown of the installation cost is presented in Table 4. The yearly operating and maintenance costs breakdown estimated by the Sunbury Steam Electric Station Plant Superintendent is given in Table 5. These costs, excluding complete baghouse bag replacement material and labor costs, for the four baghouses for 1973 and 1974 were $0.037 and $0.036 per acfm based on the design flow rate of 222,000 acfm per baghouse. Table 5 shows that the mechanical maintenance costs have been increasing while the electrical maintenance costs have been decreasing. This is believed to reflect some electrical problems during and after start-up and wearing of the collapse air fans as they get older. The approximate dimensions of each baghouse are

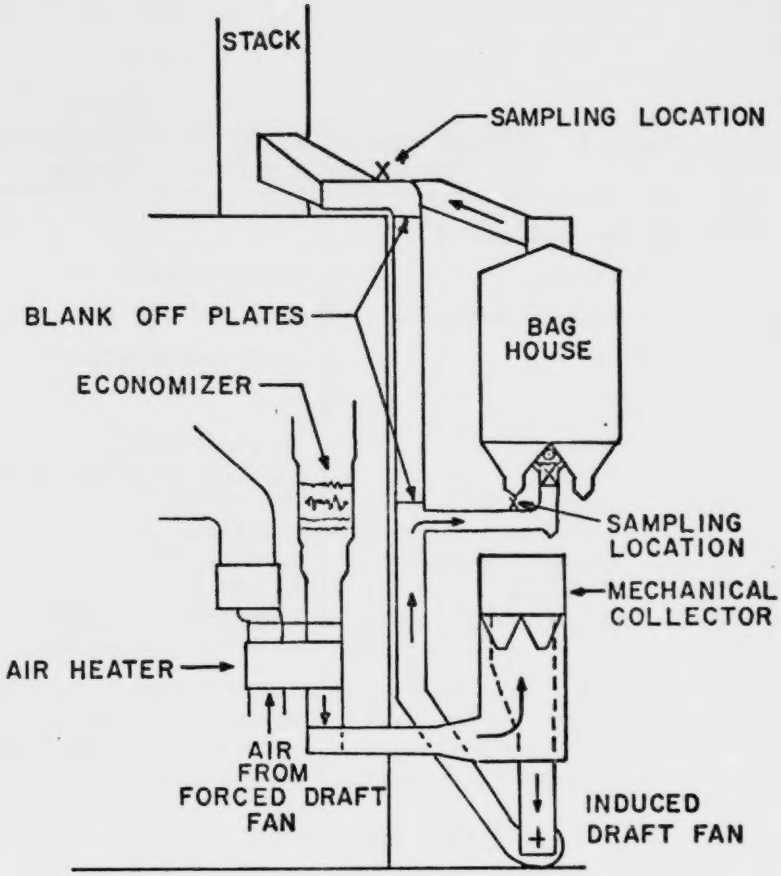

STACK
SAMPLING LOCATION
BLANK OFF PLATES
BAG HOUSE
ECONOMIZER
SAMPLING LOCATION
MECHANICAL COLLECTOR
AIR HEATER
AIR FROM FORCED DRAFT FAN
INDUCED DRAFT FAN

Figure 1. Location of dust removal equipment and sampling ports

Table 3. WESTERN PRECIPITATION DESIGN CONDITIONS FOR SUNBURY STEAM ELECTRIC STATION

Design conditions[a]	
Process	Steam boilers
Suspended material	Fume and fly ash
Fuel	Coal (anthracite)
Gas:	
Source	Steam boiler
Volume	222,000 acfm[b] per filter
Temperature	270 to 350°F
Pressure	Positive
Pressure drop	5 inches H_2O
Moisture	15.5%
Inlet grain loading	2 grains per cubic foot

[a] Source: Western Precipitation Division of Joy Manufacturing Co. Operating Instructions for Therm-o-Flex Filters for Pennsylvania Power and Light Company, Sunbury, Pennsylvania.

[b] Actual cubic feet per minute.

Table 4. SUNBURY STEAM ELECTRIC STATION BAG FILTER INSTALLATION COST BREAKDOWN

Expenditure description	Material cost, $	Labor cost, $	Total cost, $
Western Precipitation contract			
Four baghouses	1,266,985	1,020,000	2,286,985
Design and engineering - baghouse			493,400
Design and engineering - hopper enclosures			69,740
Vacuum cleaning system	30,415	43,820	74,235
Extra platforms, caged ladders, etc.	95,105	21,205	116,310
Supplements and contingencies			161,030
Subtotal - Western Precipitation contract			3,201,700
Land and land rights			1,500
Subtotal - land and land rights			1,500
Structures and improvements			
Foundation - baghouse	37,800	45,900	83,700
Clearing site			
Ash lines		9,200	9,200
Seal water line		500	500
Electric conduit cable		87,200	87,200
Storm drain and sewer line		6,900	6,900
Grading (crushed stones)	2,000	3,000	5,000
Pump house			
Foundation	6,600	7,000	13,600
Superstructure	40,000	37,000	77,000
Drainage system	6,500	7,900	14,400
Light and power system	16,500	2,700	19,200
Heating system	3,700	1,600	5,300
Precipitator roof alterations	17,500	32,600	50,100
Subtotal - structures and improvements			372,100

Table 4 (continued). SUNBURY STEAM ELECTRIC STATION BAG FILTER INSTALLATION COST BREAKDOWN

Expenditure description	Material cost, $	Labor cost, $	Total cost, $
Boiler plant equipment			
Ash removal system - bag filter			
Piping and fittings	190,000	135,000	325,000
High capacity intake and accessories	50,200	37,000	87,200
Electrical connections	1,500	1,000	2,500
Ash slurry systems			
Piping, valves and fittings	175,000	113,400	288,400
Slurry tank and accessories	11,400	4,600	16,000
Pumps and drives	57,000	26,300	83,300
Electrical connections	500	400	900
Raw water pump			
Foundations	7,700	7,000	14,700
Pumps and drives	15,400	7,000	22,400
Piping, valves and fittings	28,500	16,700	45,200
Electrical connections	2,500	900	3,400
Booster pumps			
Foundation	4,400	10,500	14,900
Pumps and drives	24,600	7,900	32,500
Piping, valves and fittings	12,500	15,000	27,500
Electrical connections	3,500	1,500	5,000
Mechanical hoppers - expansion	26,400	59,400	85,800
Multiclones in mechanical collectors - replacement		51,000	51,000
Piping for extended mechanical hopper	700	3,900	4,600
Air piping, valves and fittings	6,800	10,500	17,300
Platforms and walkways	21,500	40,900	62,400
Subtotal - boiler plant equipment			1,190,000

Table 4 (continued). SUNBURY STEAM ELECTRIC STATION BAG FILTER INSTALLATION COST BREAKDOWN

Expenditure description	Material cost, $	Labor cost, $	Total cost, $
Accessory electric equipment			
Conduit	4,000	11,000	15,000
Power cable	7,900	10,900	18,300
Control cable	23,500	14,400	37,900
Subtotal - accessory electric equipment			71,700
Miscellaneous power plant equipment			
Communication - public address system	200	100	300
Subtotal - miscellaneous power plant equipment			300
Overhead			
Engineering and supervision - indirect			109,400
Contract engineering			15,000
Engineering and supervision - direct			
Civil			75,000
Mechanical			85,800
Electrical			37,000
Cost analysis and inspection			64,500
Allowance for funds used during construction			240,000
Temporary construction power			6,000
Construction supervision			10,000
Removal cost			23,100
Salvage recovered			3,000 (Credit)
Subtotal - overhead			662,800
Total construction costs			5,500,100[a]

[a] Bulk of payment was made October 1971 through October 1973.

Table 5. ESTIMATED OPERATING AND MAINTENANCE COSTS OF THE SUNBURY STEAM ELECTRIC STATION BAGHOUSES

Cost description	1973 cost, $	1974 cost, $	First 6 months 1975 cost, $	Costs incurred through June 1975, $
Collapse fans power consumption	18,600	18,600	9,300	46,500
Air compressor power consumption	insignificant	insignificant	insignificant	insignificant
Complete bag replacement[a]				
Boiler 1A				
Material			48,000	48,000
Labor			11,000	11,000
Boiler 2A				
Material		48,000		48,000
Labor		11,000		11,000
Boiler 2B				
Material			48,000	48,000
Labor			11,000	11,000
Instrument Department labor	950	950	450	2,350
Mechanical Maintenance labor	2,130	5,840	6,270	14,240
Electrical Maintenance labor	7,410	3,800	2,910	14,120
Construction Department labor	3,950	2,350	—	6,300
Total costs, $	33,040	90,540	136,930	260,510
Total costs for designed acfm, $	0.0372	0.1020	0.1542	0.2934

[a] Boiler 1B baghouse is still operating with the original filter bags.

80 feet long, 40 feet wide and 62 feet high, including the dust hopper. Each baghouse is divided into 14 compartments which are arranged in two rows with 7 compartments per row. The physical layout of the baghouse is shown in Figure 2. The bags are arranged in each compartment in six rows with 15 bags per row. The six rows are divided into two sections by a walkway. Each filter bag is 30 feet long and 12 inches in diameter and has seven anti-deflation rings which prevent choking during cleaning. The bags are tensioned to their normal operating tension of 50 pounds by a spring. The total number of bags per bag filter is 1,260 with a total filter area of 115,668 square feet and an active filter area of 107,406 square feet. The active area is defined as the filter area in use when one compartment is out of service due to cleaning. At the baghouse design flow of 222,000 acfm, the total and active filter areas result in a face velocity of 1.919 ft/min and 2.067 ft/min, respectively.

Each baghouse compartment contains 90 bags fabricated by Menardi-Southern Company from Teflon-coated fiberglass cloth. The manufacturer's specifications for the fabric material are as follows:

- Weight = 9.5 oz/yd^2
- Thread count = 54 x 30
- Weave = 3 x 1 twill
- Frasier permeability at 0.5 in. H_2O = 75 cfm/ft^2
- Mullen burst strength = 595 psi.

Samples of new and used bags that were examined at GCA appeared to be identical except that the new fabric was woven with a left-hand diagonal while the used fabric was woven with a right-hand diagonal. Since this, in effect, produces only a mirror image, there is no reason to expect any difference in fabric performance.

The results of the physical characterization tests performed on the new and used bags are presented in Table 6. These tests show that the used bags' air permeability is much less than that for a new bag which is probably due to dust particles lodged in the fabric interstices.

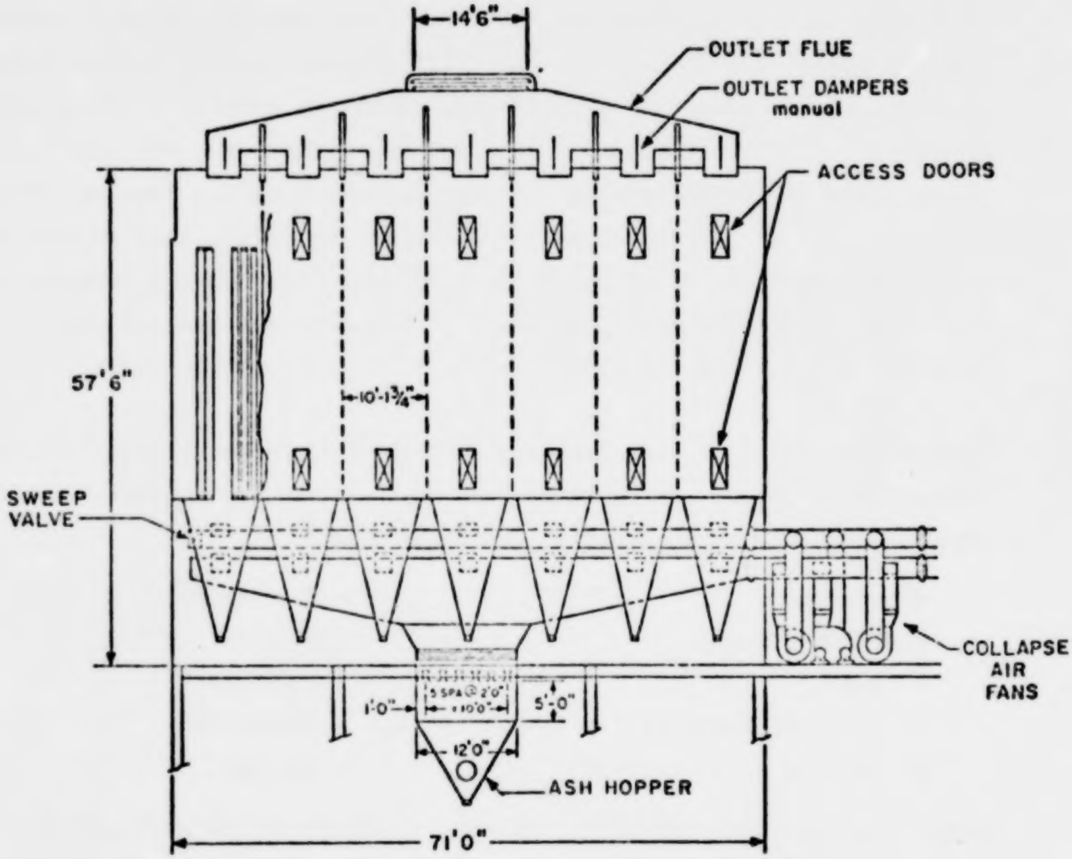

14'6"
OUTLET FLUE
OUTLET DAMPERS
manual
ACCESS DOORS
57'6"
10'-1¾"
SWEEP
VALVE
COLLAPSE
AIR
FANS
5 SPA @ 2'0"
= 10'0"
1'0"
5'-0"
12'0"
ASH HOPPER
71'0"

Figure 2. Sunbury Steam Electric Station baghouse 1A

Table 6. RESULTS OF PHYSICAL CHARACTERIZATION TESTS ON FABRIC FILTER BAGS

Test description	New bag	Used bag #1	Used bag #2	Used bag #1, vacuum cleaned	Used bag #2, vacuum cleaned
ASTM D 1910, Sample weight, oz/sq yd	11.0	16.9	13.5	11.5	11.3
ASTM D 1777, Sample thickness, mils					
Range	10.3 - 13.0	15.6 - 18.6	13.7 - 14.7	12.8 - 14.8	11.7 - 13.0
Average	11.2	16.9	14.2	13.6	12.5
ASTM D 737, Air permeability, cfm/sq ft at ½" H_2O ΔP					
Range	49.5 - 58.0	0.7 - 1.5	1.1 - 2.1	28.0 - 31.4	35.7 - 44.1
Average	54.3	1.1	1.6	30.5	40.0
ASTM D 1602, Breaking strength and elongation					
Breaking strength, lb					
Warp: Range	187 - 200	137 - 200	123 - 167		
Average	197	166	152	194	186
Fill: Range	82 - 93	111 - 132	86 - 142		
Average	87	121	116	117	134
Elongation at break, percent					
Warp: Range	3.1 - 3.9	3.6 - 3.9	2.1 - 3.6		
Average	3.5	3.8	3.2	3.4	3.2
Fill: Range	2.6 - 2.8	2.8 - 2.9	1.9 - 2.2		
Average	2.6	2.9	2.1	2.0	2.3
Average energy to break, inch-lb					
Warp:	3.4	3.2	2.4	3.4	2.9
Fill:	1.1	1.8	1.2	1.2	1.5
Average:	2.3	2.5	1.8	2.3	2.2
Flexural rigidity-beam method, (10^{-3})lb/sq in. per inch of width					
As received					
Warp:	0.41, 0.47	1.5 , 2.1	1.5, 1.1		
Fill:	0.73, 0.73	3.0 , 2.4	1.9, 2.0		
Average:	0.58	2.2	1.6		
Adjusted for difference in mass					
Warp:	0.41, 0.47	0.98, 1.4	1.2, 0.89		
Fill:	0.73, 0.73	1.9 , 1.6	1.6, 1.6		
Average:	0.58	1.5	1.3		

The tests also show that the strength of the fabric even after 2 years' use is not substantially reduced, indicating that very little damage or wear has occurred. It was also found that the used fabric was not as flexible as the new medium, presumably due to the particles in the interstices of the fabric. With respect to the increases in the breaking strength of the cleaned fabric (warp direction) and the used fabric (fill direction), it is suspected that the increased breaking strength in the warp direction after cleaning was due to the removal of some of the abrasive dust particles. The greater breaking strength of the fabric in the fill direction was attributed to the interstitial deposition of particles which acted as strengthening agents by suppressing the relative motion of the fibers within the yarn.

Dust is removed from the bags by reversing the gas flow through a compartment. This is accomplished by first closing the compartment inlet damper and then opening the collapse air damper which connects the compartment inlet to the suction of a collapse air fan rated at 12,500 cfm at 300°F. The collapse air fan draws the cleaned gas from the outlet manifold through the compartment and through the collapse air damper and exhausts the collapse air into the inlet manifold. Figure 3 shows the damper positions and the gas flow during normal filtering and cleaning. The dust which is removed from the bags accumulates in the hopper and is periodically removed by a pneumatic conveying system. The dust in the pneumatic conveying system is combined with water to form an ash slurry which is pumped to a settling basin.

During normal operation, it takes approximately 33 minutes to complete a cleaning cycle, which consists of the sequential cleaning of each of the 14 baghouse compartments and two sweep cleanings of the collapse air duct. These cleaning cycles are continuous with the completion of one cycle coinciding with the initiation of the next cycle. Each cleaning cycle's sequence of events and its time intervals are presented in Table 7.

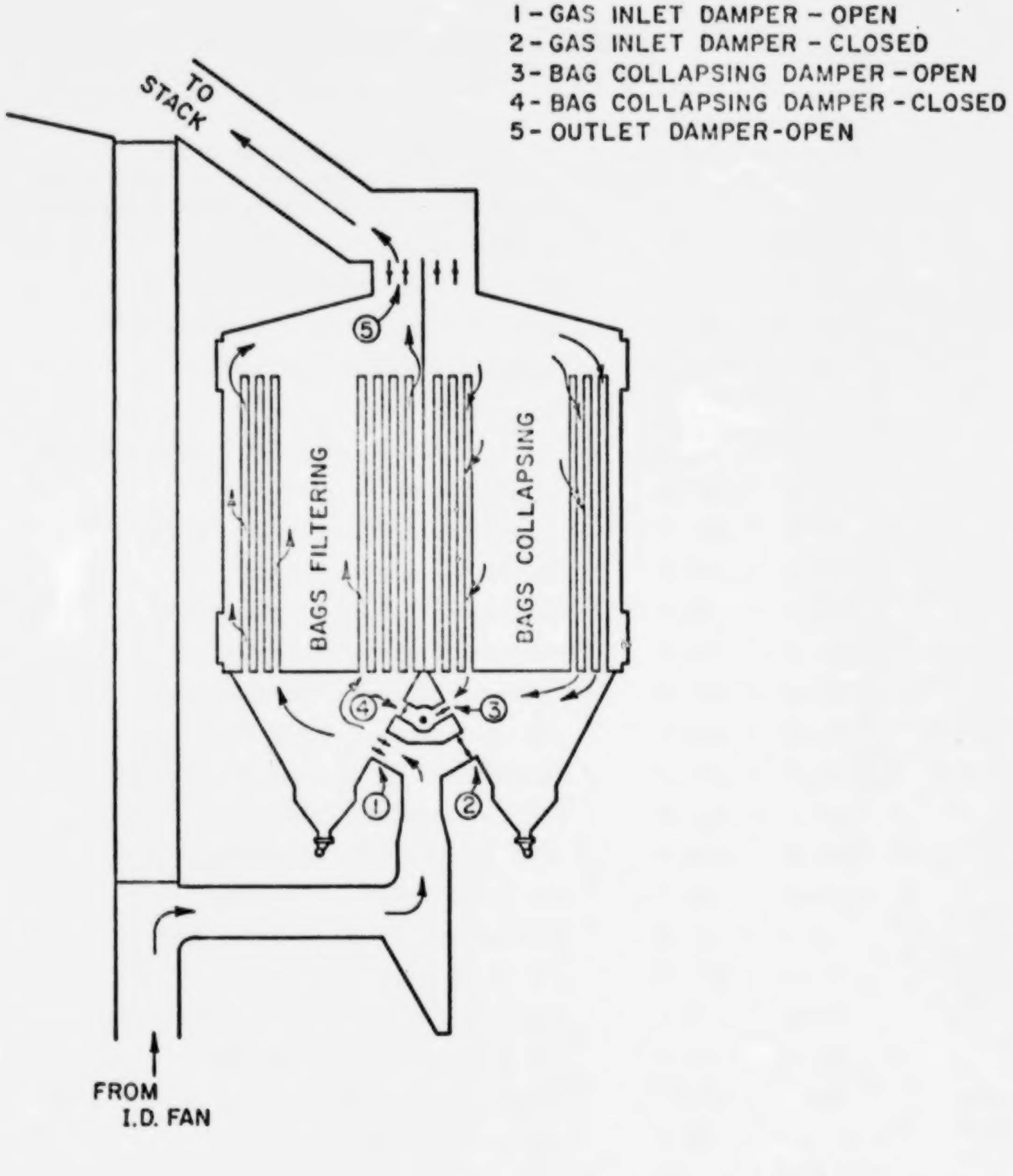

1 - GAS INLET DAMPER - OPEN
2 - GAS INLET DAMPER - CLOSED
3 - BAG COLLAPSING DAMPER - OPEN
4 - BAG COLLAPSING DAMPER - CLOSED
5 - OUTLET DAMPER-OPEN
TO STACK
BAGS FILTERING
BAGS COLLAPSING
1
2
3
4
5
FROM I.D. FAN

Figure 3. Gas flow through baghouse compartments during normal operation and cleaning

Table 7. SEQUENCE OF EVENTS OCCURRING DURING NORMAL CLEANING CYCLE

Elapsed time duration, seconds	Event in cleaning cycle
0 - 2.0	Compartment #1 gas inlet damper closing
2.0 - 16.0	Settling
16.0 - 17.0	Collapse air damper opening
17.0 - 68.0	Reverse flow through Compartment #1
68.0 - 69.5	Collapse air damper closing
69.5 - 81.0	Settling
81.0 - 83.0	Compartment #1 gas inlet damper opening
83.0 - 122.0	All compartments filtering
122.0 - 205.0	Compartment #2 in cleaning mode
205.0 - 244.0	All compartments filtering
244.0 - 327.0	Compartment #3 in cleaning mode
327.0 - 366.0	All compartments filtering
366.0 - 449.0	Compartment #4 in cleaning mode
449.0 - 488.0	All compartments filtering
488.0 - 571.0	Compartment #5 in cleaning mode
571.0 - 610.0	All compartments filtering
610.0 - 693.0	Compartment #6 in cleaning mode
693.0 - 732.0	All compartments filtering
732.0 - 815.0	Compartment #7 in cleaning mode
815.0 - 855.0	All compartments filtering
855.0 - 935.0	Collapse air duct sweep value open
935.0 - 980.0	All compartments filtering
980.0 - 1063.0	Compartment #8 in cleaning mode
1063.0 - 1102.0	All compartments filtering
1102.0 - 1185.0	Compartment #9 in cleaning mode
1185.0 - 1224.0	All compartments filtering

Table 7 (continued). SEQUENCE OF EVENTS OCCURRING DURING NORMAL CLEANING CYCLE

Elapsed time duration, seconds	Event in cleaning cycle
1224.0 - 1307.0	Compartment #10 in cleaning mode
1307.0 - 1346.0	All compartments filtering
1346.0 - 1429.0	Compartment #11 in cleaning mode
1429.0 - 1468.0	All compartments filtering
1468.0 - 1551.0	Compartment #12 in cleaning mode
1551.0 - 1590.0	All compartments filtering
1590.0 - 1673.0	Compartment #13 in cleaning mode
1673.0 - 1712.0	All compartments filtering
1712.0 - 1795.0	Compartment #14 in cleaning mode
1795.0 - 1835.0	All compartments filtering
1835.0 - 1915.0	Air sweep cleaning of collapse air duct
1915.0 - 1960.0	All compartments filtering

The ability of the bag collapse and reverse flow type of cleaning to accomplish adequate cleaning was determined by studying the time history of the pressure drop across the baghouse, which is presented in Figure 4. Insufficient cleaning would be indicated by a rapid increase in the pressure drop across the baghouse to the 5" H_2O pressure drop limitation of the induced draft fans. Although there is a steady increase in pressure drop with time, the increase is very gradual. Extrapolating the line of best fit drawn through all the points of Figure 4, excluding the February and March 1973 points, the 5" H_2O limiting pressure drop across the baghouse will not be exceeded for several years. If the bag life were found to be shortened by chemical aging or other factors, it might be practical to reduce the cleaning energy and let the pressure drop increase more steeply. The reduced cleaning energy savings, however, would have to be weighed against the increased power consumption of the induced draft fan caused by the higher pressure drop.

Transient variations in the pressure drop across each baghouse were recorded on circular charts at Sunbury, a sample copy of which is presented in Appendix G. It should be noted that the trace for boiler 1B baghouse was purposely displaced to indicate a pressure drop of 5" H_2O, when the actual pressure drop across the baghouse was 0" H_2O, to avoid overlapping the traces. The pressure oscillations which caused the traces to have a thick band-like appearance were caused by compartment cleaning, and the changes which caused the band to shift to higher or lower pressure drops were the results of changes in the amount of combustion air reflecting changes in load.

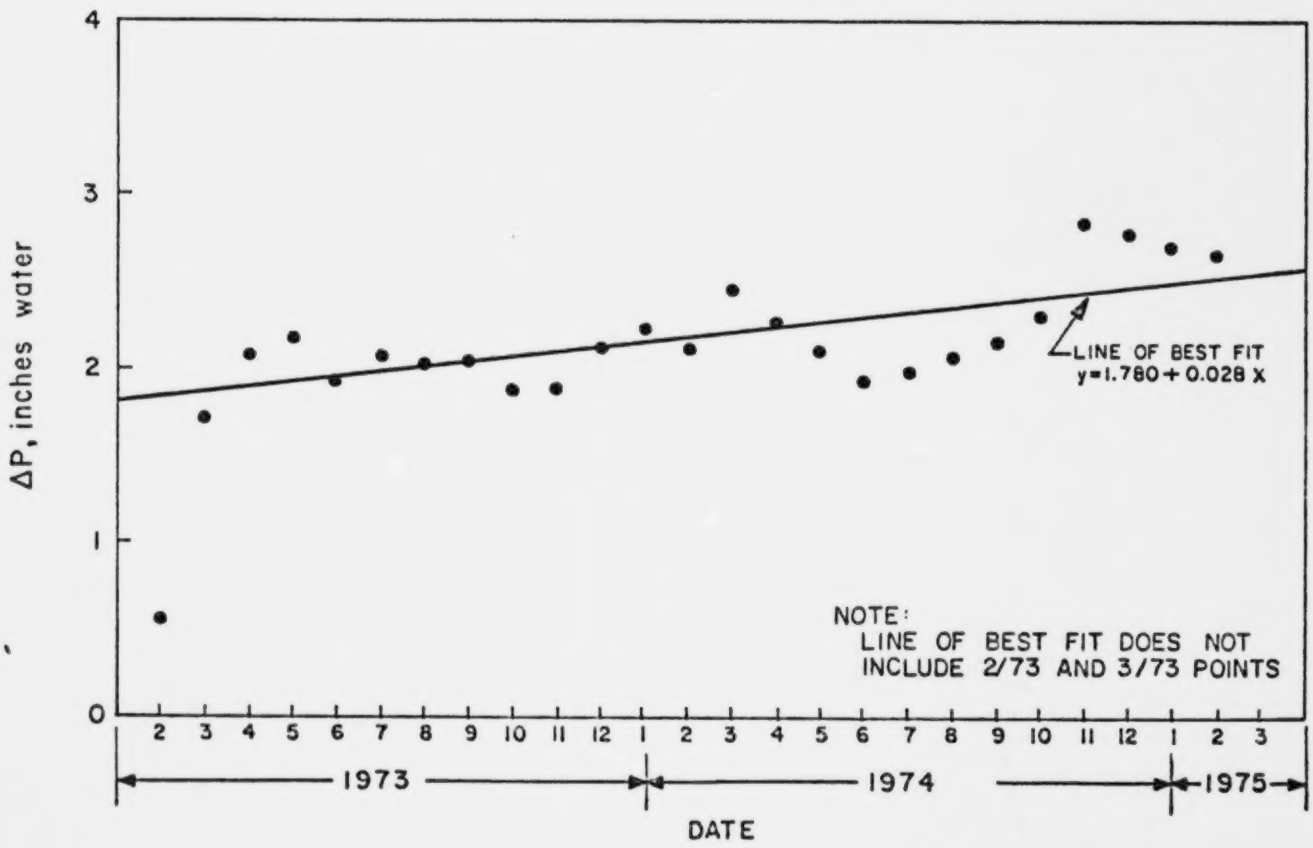


Figure 4. 1A baghouse pressure differential history

SECTION V

EQUIPMENT AND METHODS

The baghouse at the Sunbury Steam Electric Station was evaluated for the total particulate penetration and the particle penetration as a function of size. Total mass samples and size-classified samples were collected before and after the baghouse. A condensation nuclei counter and diffusion denuder were used to determine the penetration of submicron particles. Flue gas composition was monitored by an instrumented EPA trailer. In addition, pulverized coal samples were extracted from the feed line between the pulverizer and the boiler.

Since most of the sampling methods employed were straightforward, they do not require extensive descriptions. Only the novel or unusual techniques, including some designed by GCA, will be described in detail.

MASS MEASUREMENTS

The baghouse inlet mass concentration was determined by collecting a sample isokinetically utilizing a RAC Staksamplr.^{TM} The locations of the inlet sampling ports in relation to upstream and downstream disturbances are shown in Figure 5. It was possible to sample only four of the six inlet ports because of the proximity of one of the baghouse compartment dust hoppers. The vertical distance from the top of the sample port nipple to the point of contact with the hopper was 6 feet, thus preventing use of the 8-foot probe, the latter being required because the duct was 5 feet deep and the port nipples were 2 feet long.

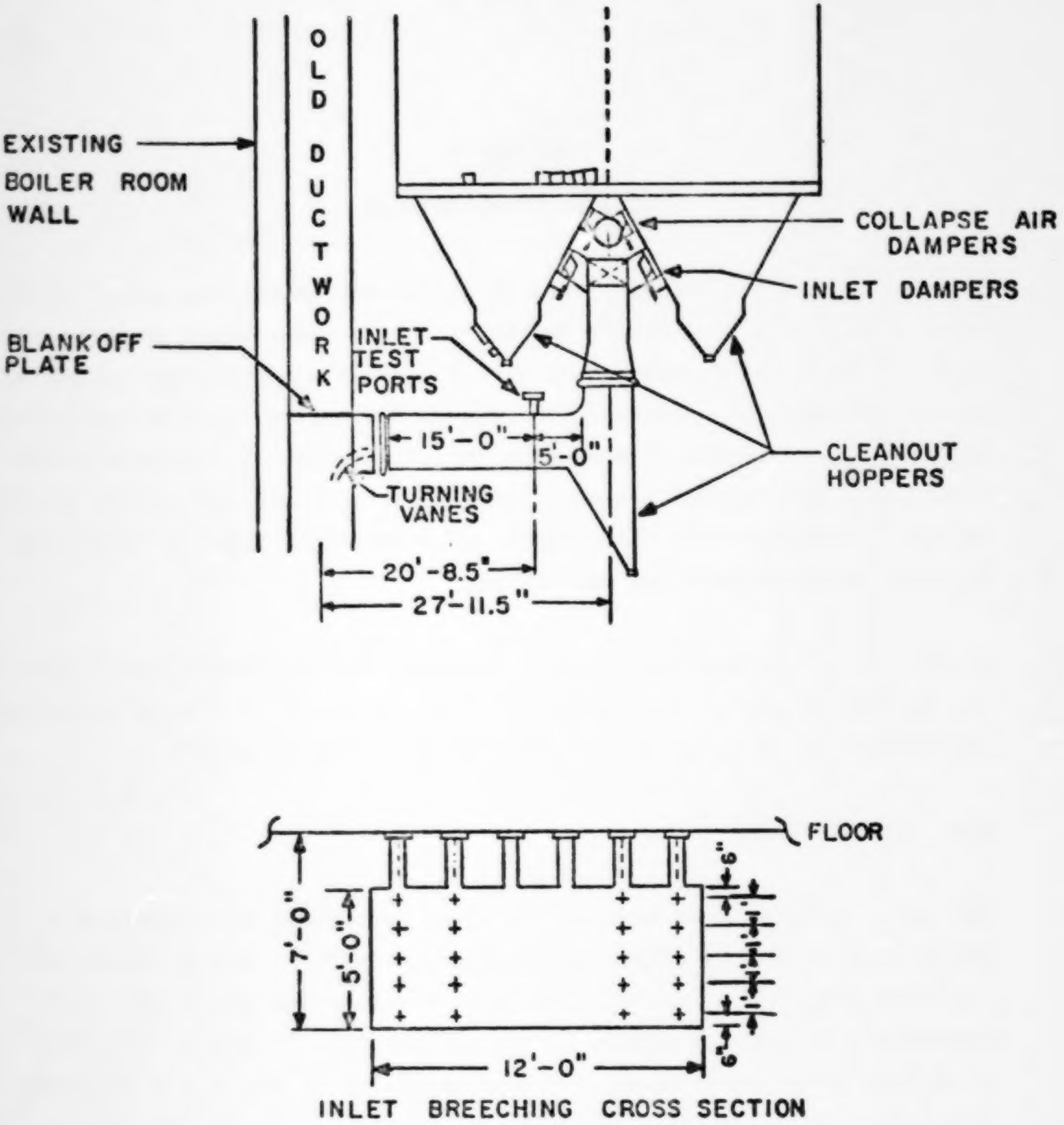
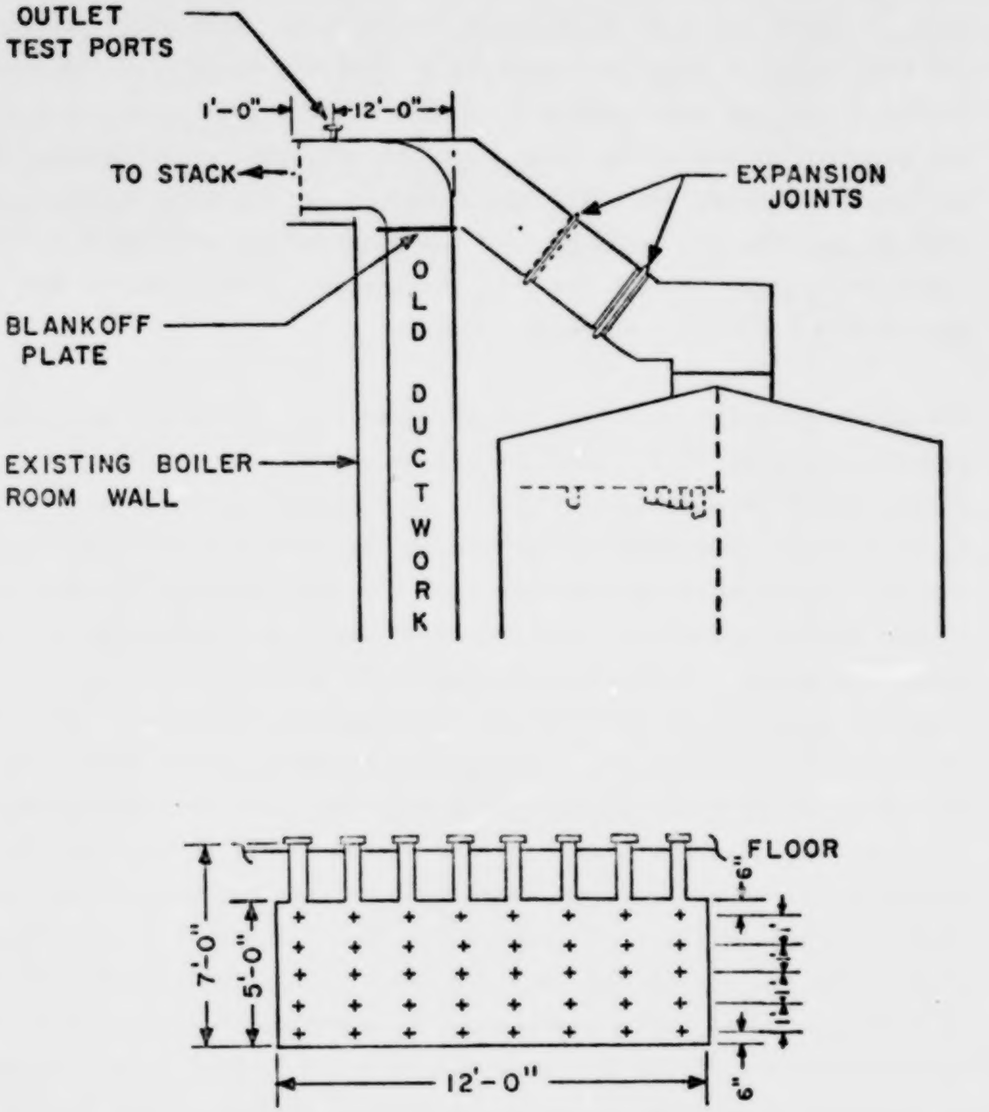

EXISTING BOILER ROOM WALL
OLD DUCTWORK
BLANK OFF PLATE
INLET TEST PORTS
COLLAPSE AIR DAMPERS
INLET DAMPERS
CLEANOUT HOPPERS
TURNING VANES
15'-0"
5'-0"
20'-8.5"
27'-11.5"
FLOOR
7'-0"
5'-0"
6"
6"
12'-0"
INLET BREECHING CROSS SECTION

Figure 5. Location of baghouse inlet test ports and sampling points

It was also impossible to insert the 8-foot probe at an angle because of other outside interfering structures. The exact locations of the inlet points sampled are also illustrated in Figure 5. Each inlet sample point was sampled for 5 minutes, requiring a total sample time of 110 minutes. Initially, it had been planned to sample for the same time duration at the inlet as at the outlet to account for any temporal variations in loading. This plan was modified to shorten the exposure of the sampling crew to the flue gas escaping from the positive pressure inlet duct. The excessive leakage of flue gas into the working space required that respirators be worn while changing ports.

The outlet mass concentration was determined by isokinetically sampling with an Aerotherm High Volume Stack Sampler which is basically the same as the RAC Staksamplr except that it is designed to sample at flow rates up to 6 acfm.[3] The higher flow rate of the Aerotherm makes it especially suitable for sampling gas streams with low dust loadings because the increase in mass collection rate decreases the time required to collect a weighable sample. In Sunbury, however, it was the mass collected on the impactor stages which dictated the sampling time necessary. The location of the outlet sampling ports in relation to upstream and downstream disturbances is shown in Figure 6 along with the array of sampling points. All eight sampling ports were sampled during the first few tests with the bottom points on ports 1 and 8 purposely omitted because of vacuuming dust off the duct floor at these points during a previous compliance test.[4] The results of two Aerotherm tests (Runs 2 and 3) were negated when unexplainably high outlet mass concentrations coincided with inadvertent sampling of the bottom points on ports 1 and 8. For the majority of the testing program the points in ports 2 through 7 were sampled at 10 minutes per point for a total sample time of 300 minutes.


OUTLET TEST PORTS
1'-0"
12'-0"
TO STACK
EXPANSION JOINTS
BLANKOFF PLATE
OLD DUCTWORK
EXISTING BOILER ROOM WALL
FLOOR
7'-0"
5'-0"
6"
12'-0"
6"

OUTLET BREECHING CROSS SECTION

Figure 6. Location of baghouse outlet test ports and sampling points

IMPACTOR MEASUREMENTS

The penetration of particles through the bag filter as a function of size and the inlet and outlet particle size distributions over the range of approximately 0.5 μm to 20 μm were determined using inertial impactors. The two types of impactors used were the Andersen Mark III Stack Sampler and the University of Washington (U of W) Mark III Source Test Cascade Impactor.

The baghouse inlet was sampled with an Andersen Impactor with a cyclone precollector. The sample was withdrawn isokinetically from the middle point in port No. 4. Both inlet and outlet ports were arbitrarily numbered from north to south. The purpose of the precollector was to remove the larger particles, thus preventing the overloading of the upper impactor stages and permitting a longer impactor sampling time. The results of the first few tests indicated that the maximum sampling time would be approximately 3 minutes. During the first 21 tests, two impactor runs were made per day. When the inlet cumulative size distribution curves were plotted for the first 21 runs, it was observed that the size distribution curves were nearly vertical for the larger particles, indicating that the cyclone precollector was collecting a large portion of the particles which would normally have been impacted on the upper impactor stages. In an attempt to determine what portion of the particles were being removed from the upper stages by the precollector, an extra inlet impactor sample was taken during each of the remaining runs. The extra impactor sampled through a 90° gooseneck nozzle instead of the cyclone precollector. Upon examination of the cumulative size distribution curves for runs 22 through 31, it was evident that there wasn't a consistent difference between the size distribution measured by the Andersen with the precollector and by the Andersen with the gooseneck nozzle. The mean percentage of the mass caught in the impactor precollector for tests 22 through 31 was 34.88 with a standard deviation of 9.34, while the mean percentage of the mass caught in the impactor gooseneck nozzle for the same series of tests was 33.22 with a standard deviation of 5.39. Therefore, it was impossible to determine the portion of particles that would have impacted on the upper impactor stages if they were not collected by the cyclone precollector. It appeared that the gooseneck nozzle removes approximately the same fraction of the sample as the cyclone precollector.

Two cascade impactors sampled the baghouse effluent simultaneously during each run. These samples were extracted from the middle points of the ports rather than by traverse. It was necessary to change ports once during each run to allow the Aerotherm sampler to make a complete traverse. Usually, the two impactors sampled three ports — the first, ports No. 3 and 4 and the second, ports No. 4 and 5. Prior to initiation of sampling, the gas velocities at the sampling points were measured and averaged to determine the impactor nozzle flow rate needed for isokinetic sampling.

Both Andersen and U of W impactors were used to sample the baghouse effluent. Originally, only Andersen impactors were used, but after the first few runs, it was noticed that the substrate weight gains were much greater than would be expected based on visual inspection. It was suspected that the unusual weight gains were related to gas adsorption on the Andersen glass fiber substrates. In order to test the theory that the substrates were gaining weight other than from fly ash, an impactor was loaded and run with two substrates on each impactor stage. When the substrates were weighed, both the top substrate, which was nearest the incoming gas stream, and bottom substrate on each impactor stage gained weight indicating an anomalous (with respect to particulate) weight gain. Subsequently, all Andersen impactors were loaded with two sets of impactor substrates so that the anomalous weight gain could be corrected for by subtracting the weight gained by the bottom substrate from the weight gained by the top substrate. To gain more conclusive evidence of anomalous weight gains, a 47-mm type A (for manufacturer's specifications, see reference 5) glass fiber filter was placed on the impactor inlet causing the impactor to sample particle-free flue gas. All the impactor substrates continued to gain weight, indicating that the anomalous weight gains were presumably due to gas ad- or absorption. The Andersen with a prefilter was also run when loaded with two sets of substrates to determine if the same weight was gained by both of the substrates on a stage. The results presented in Table 8 show that the weight gained by the top substrate on each impactor stage was always greater. Therefore, when the weight gained by the bottom substrate is subtracted from the top substrate, not all the anomalous weight gain is accounted for, and the mass concentrations determined by the outlet Andersen impactors are higher than actual. Figure 7 shows the relationship between mass concentration as determined by impactor and total mass sampler. The high percentage of impactor mass concentrations, which were greater than the Aerotherm mass concentrations, shows that all the anomalous weight gain was not corrected for. Recent investigations by Smith et al.[6] have found that most of the anomalous weight gains were the result of sulfate uptake on the substrates.

A second approach to the anomalous weight gain problem was to sample with a University of Washington Mark III impactor which does not employ glass fiber substrates as impaction surfaces. The U of W impactor uses stainless steel inserts coated with grease as the impaction surfaces. Initially, the inserts were coated with Dow Corning high vacuum grease which was recommended by the impactor manufacturer. The Dow Corning grease was unsatisfactory because the greased inserts lost weight during sampling which was probably due to decomposition of the grease during the long (6-hour) exposure time to the hot stack gases. After some experimentation, inserts coated with polyethylene glycol and dried in a 300°F oven overnight were found to be satisfactory. The correlation between the outlet mass concentrations determined by the Aerotherm

Table 8. RESULTS OF RUNS MADE WITH PREFILTER ON ANDERSEN

Run 7	Substrate weight gain, grams			Run 17	Substrate weight gain, grams			Run 18	Substrate weight gain, grams			Run 20	Substrate weight gain, grams		
Stage	Top	Bottom	Top - Bottom	Stage	Top	Bottom	Top - Bottom	Stage	Top	Bottom	Top - Bottom	Stage	Top	Bottom	Top - Bottom
Prefilter	0.0057	No		Prefilter	0.0045			Prefilter	0.0037			Prefilter	0.0031		
0	0.0044	Double		0	0.0063	0.0033	0.0030	0	0.0050	0.0024	0.0026	0	0.0063	0.0036	0.0027
1	0.0015	Substrate		1	0.0064	0.0029	0.0035	1	0.0047	0.0024	0.0023	1	0.0023	0.0026	0.0035
2	0.0039			2	0.0052	0.0018	0.0034	2	0.0042	0.0019	0.0023	2	0.0053	0.0015	0.0038
3	0.0026			3	0.0043	0.0020	0.0023	3	0.0028	0.0016	0.0012	3	0.0045	0.0018	0.0027
4	0.0022			4	0.0021	0.0010	0.0011	4	0.0028	0.0017	0.0011	4	0.0033	0.0009	0.0024
5	0.0016			5	0.0017	0.0008	0.0009	5	0.0020	0.0016	0.0004	5	0.0022	0.0013	0.0009
6	0.0016			6	0.0012	0.0005	0.0007	6	0.0018	0.0014	0.0004	6	0.0017	0.0009	0.0008
7	0.0001			7	0.0010	0.0006	0.0004	7	0.0013	0.0012	0.0001	7	0.0014	0.0011	0.0003
F	0.0006			F	0.0006	0.0003	0.0003	F	0.0019	0.0000	0.0019	F	0.0022	0.0005	0.0021

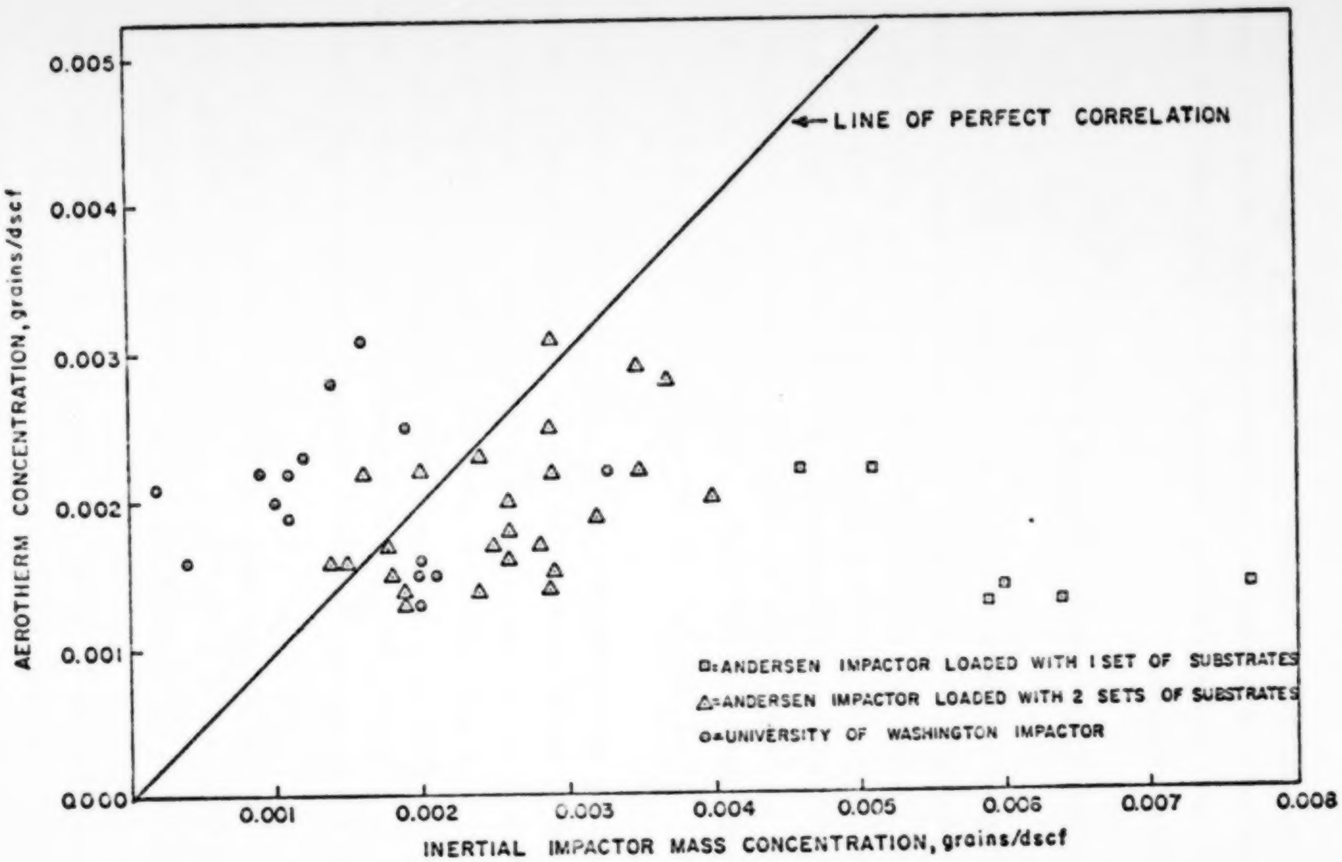


Figure 7. Correlation between the outlet mass concentrations determined by the Aerotherm High Volume Stack Sampler and the inertial impactors

sampler and the U of W impactor is also shown in Figure 7. The large percentage of U of W impactor mass concentrations, which were lower than Aerotherm mass concentrations, indicates that there might have been some grease deterioration.

CONDENSATION NUCLEI COUNTER MEASUREMENTS

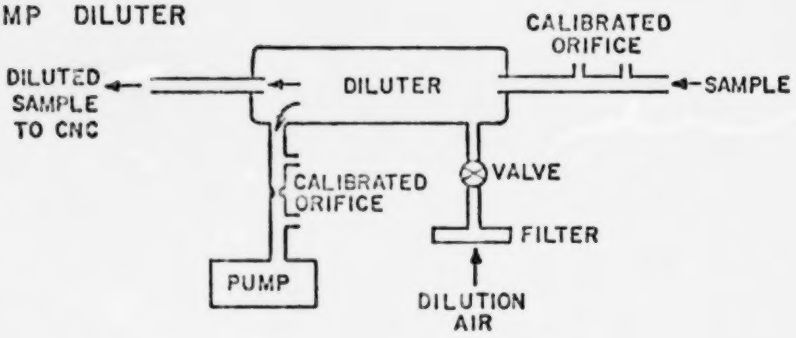
The penetration of submicron particles through the baghouse was determined by sampling the effluent stream before and after the baghouse with a Condensation Nuclei Counter (CNC) and a Diffusion Denuder (DD). The particle concentration was measured by a Rich Model 100 CNC and the particle sizing was determined using a DD with the CNC. The CNC measures particles of 0.0025 μm and larger diameter[7] in the concentration range of 1,000 to 300,000 particles/cc. The theoretical upper size limit measurable by the CNC has been estimated to be 0.3 to 0.5 μm.[8]

When sampling an aerosol that has a very large number of submicron particles, it is often necessary to dilute the sample stream so the concentration is within the CNC's measurement range. In addition, when sampling a hot, corrosive flue gas, substantial cooling and dilution of the sample stream must be accomplished to protect the CNC internal gas passages. Diluters provided the necessary cooling without subsequent condensation which results in the removal of submicron particles.

Four diluter designs were employed, all requiring dilution of a metered sample stream with a metered amount of filtered air. The measured flow rates enable calculation of the dilution of the sample stream.

The pump diluter shown in (a) of Figure 8 draws a sample through an orifice into the diluter body where the sample flow mixes with a regulated flow of filtered dilution air. The major portion of the diluted sample is drawn through an orifice by a pump and exhausted, while the

(a) PUMP DILUTER


CALIBRATED ORIFICE
DILUTED SAMPLE TO CNC
DILUTER
SAMPLE
CALIBRATED ORIFICE
VALVE
FILTER
PUMP
DILUTION AIR

(b) AIR EJECTOR DILUTER

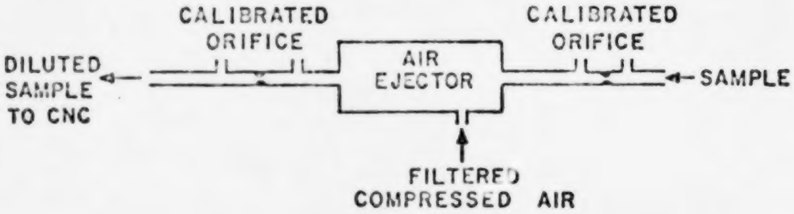
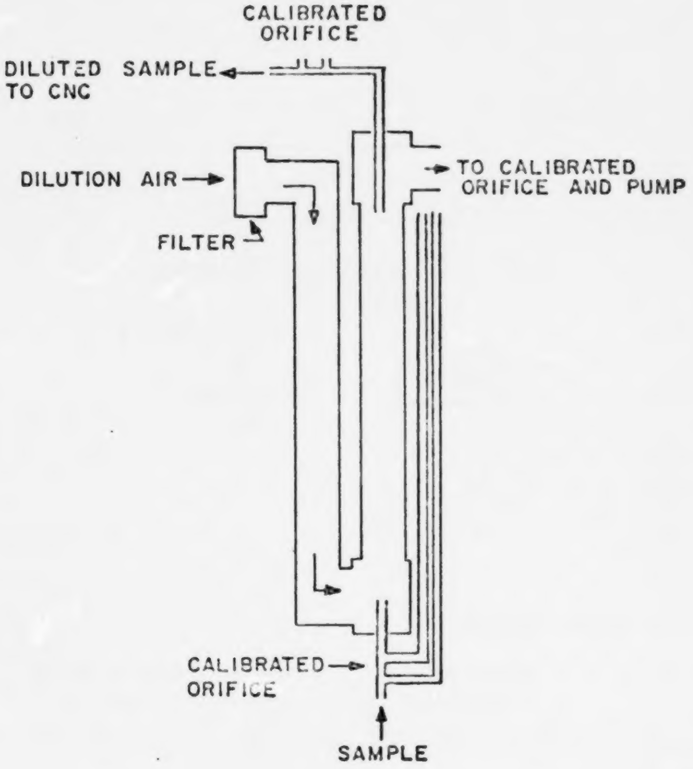

CALIBRATED ORIFICE
CALIBRATED ORIFICE
DILUTED SAMPLE TO CNC
AIR EJECTOR
SAMPLE
FILTERED COMPRESSED AIR

Figure 8. Condensation nuclei counter system components

(c) IN-STACK DILUTER


CALIBRATED ORIFICE
DILUTED SAMPLE TO CNC
DILUTION AIR
FILTER
TO CALIBRATED ORIFICE AND PUMP
CALIBRATED ORIFICE
SAMPLE

(d) CAPILLARY TUBE DILUTER

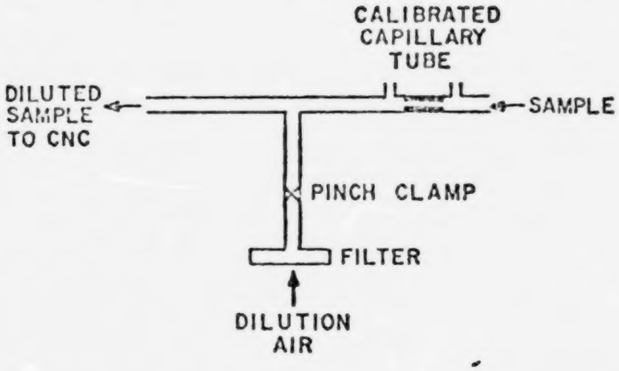

CALIBRATED CAPILLARY TUBE
DILUTED SAMPLE TO CNC
SAMPLE
PINCH CLAMP
FILTER
DILUTION AIR

Figure 8 (continued). Condensation nuclei counter system components remaining flow is drawn either directly to the CNC or through more diluters. This diluter is capable of providing a maximum dilution of approximately 375 to 1.

The air ejector diluter shown in (b) of Figure 8 is limited to a maximum dilution of approximately 10 to 1. Its main value is its ability to extract a sample from a low pressure location and to discharge the diluted sample at about atmospheric pressure. The CNC will not operate properly when the pressure of the sample entering the CNC is too far below atmospheric, ~2 in. H_2O. In the air ejector diluter, the sample is drawn through an orifice by an air ejector in which the sample stream and a filtered compressed air stream are mixed before discharge through an orifice which meters the combined flow.

During the first two series of tests, the baghouse effluent sample was drawn sequentially through a heated probe, the pump diluter, and the air ejector diluter into the CNC. Extremely high particle concentrations led to experiments to assure that the concentrations being found were representative of the concentrations in the duct. It was thought that extraneous particles might be entering the dilution system via the dilution air supply, the compressed air supply or a vacuum leak. When particle entry was checked by sampling with the dilution system sample inlet plugged, it was found that particle entry was not a problem. It was also thought that particles might be generated in the heated probe. Particle generation was checked by installing a filter holder with a type A glass fiber filter on the inlet of the sampling probe. The same concentrations were measured with and without the prefilter, thereby indicating particle generation. It was also found that the particle generation in the probe was a function of the temperature to which the probe was heated. To alleviate the particle generation problem which was believed to be caused by a condensation/evaporation type of mechanism, an in-stack diluter was designed. The main advantage of the in-stack diluter is that the undiluted sample is exposed to a minimal length of tubing before being diluted. This should result in a representative sample of the stack gas.

The in-stack diluter which is illustrated in (c) of Figure 8 draws a sample through a calibrated orifice into the diluter body where the sample flow mixes with a filtered and heated flow of dilution air. A diluted sample flow is extracted from the combined flow of sample gas and dilution air with its flow measured by a calibrated orifice. The remaining flow passes through a calibrated orifice and a pump. The range of dilutions the diluter is capable of providing is approximately 5 to 1 to 17 to 1.

During the third group of tests, the in-stack diluter and the air ejector diluter were used in series to condition the sample for the CNC. With this arrangement, the sample was withdrawn from the stack through a calibrated orifice and mixed with dilution air in the in-stack diluter. A diluted sample was extracted from the in-stack diluter and drawn through a calibrated orifice into the air ejector diluter. In the air ejector diluter the diluted sample was mixed with compressed air and discharged through a calibrated orifice. The air ejector diluter discharge was sampled and metered by the CNC. The in-stack diluter was also connected directly to the CNC. When this was done, very low concentrations were measured; this was thought to be caused by condensation resulting from insufficient dilution. When the air ejector diluter was used, the hot, diluted sample from the in-stack diluter was diluted before condensation occurred.

A capillary tube diluter, capable of providing a 12 to 1 dilution, is shown in (d) of Figure 3. A capillary tube meters the sample flow which is combined with regulated filtered dilution air in a tee. The combined sample and dilution flow is measured by the CNC rotometer. The capillary tube diluter was used primarily to vary the sample flow rates through the DD to provide sizing data.

The DD is made of three closely spaced (0.097 cm) concentric cylinders on which diffused particles are collected. The d_{50}, which is the particle diameter removed in the DD with 50 percent efficiency, is dependent upon the flow rate through the DD. The DD is most applicable for particle sizes ranging from 0.01 to 1 μm diameter.[7]

Particle sizing was accomplished by first sampling with the CNC alone which furnished concentration data for particles $\geq$ 0.0025 μm. Next, the approximately 50-cc/sec flow to the CNC was first passed through the DD, where particles smaller than 0.015 μm were retained. Finally, a 5-cc/sec flow was first passed through the DD, where particles smaller than 0.048 μm were retained. The capillary tube diluter allowed a 5-cc/sec sample to be drawn through the DD, with the remaining 45-cc/sec flow required by the CNC provided by dilution air.

GASEOUS MEASUREMENTS

The sampling and analyses of the baghouse effluent for gaseous components was performed by Research Triangle Institute personnel utilizing the National Environmental Research Center's Mobile Stack Gas Analyzer Trailer. The stack gases were monitored for oxygen, carbon dioxide, and sulfur dioxide over the duration of the tests.

The Trailer's instruments monitored a continuous flow of conditioned flue gas samples. Particulate was removed from the sample stream by an in-stack filter before passing the gas through a heated Teflon tube to maintain its temperature at 250°F. Residual moisture in the sample stream was removed by cooling the gas to approximately 34°F. A portion of the dried sample gas was pressurized and distributed to each of the instrument analyzers. The capabilities of the on-board analyzers are presented in Table 9. Each instrument was calibrated according to procedures given in the Federal Register, Volume 39, No. 177, Part II, Page 32864. In addition to the instruments in Table 9, iron constantan thermocouples measured gas temperatures with an accuracy of ± 2°F.

Table 9. CAPABILITIES OF THE MOBILE STACK GAS ANALYZER'S INSTRUMENTATION[9]

Gas component	Type of analysis	Ranges	Range levels	Approximate sensitivity
Oxygen	Paramagnetic	3	0-5/10/25%	0.05/0.1/0.25%
Carbon dioxide	Nondispersive infrared	3	0-5/10/20%	0.05/0.1/0.2%
Carbon monoxide	Nondispersive infrared	3	0-500/1000/2000 ppm	5/10/20 ppm
Sulfur dioxide	Nondispersive infrared	3	0-1000/2000/4000 ppm	10/20/40 ppm
Nitrogen oxides	Chemiluminescent	3	0-200/2000/20,000 ppm	2/20/200 ppm

COAL SAMPLING

At approximately the half-way point of each run, samples were collected of each of the three fuel components: petroleum coke, anthracite silt and anthracite number 5 buckwheat. A separate sampling of the pulverized mixture of the above constituents (the actual boiler feed) was also performed. The samples of petroleum coke, anthracite silt and anthracite number 5 buckwheat were collected by catching the coal in plastic bags as it dropped through the rotary table feeders which convey the coal from the bins to the ball mills where the coal is pulverized. It took about a minute to collect each sample from the rotary table feeders. The pulverized boiler feed was extracted from the air suspension of pulverized coal which was blown from the pulverizer directly into the boiler. The pulverized sample was collected with a sampler devised by Sunbury personnel. It consisted of a probe, a cyclone separator and a cloth bag system which operated for 30 minutes. The coal air mixture passed through the probe and into the cyclone where the pulverized coal was separated from the air and the air exhausted through a cloth bag.

SECTION VI

RESULTS

The 31 tests run at the Sunbury Steam Electric Station (S.E.S.) were broken down into three phases. The first phase was designed to study the effect of varying the fractions of anthracite silt, petroleum coke and anthracite number 5 buckwheat in the fuel mixture to the boiler. The first phase encompassed runs 1 through 10 which were performed from January 8, 1975, through January 18, 1975. The second series of tests, runs 11 through 21, were designed to study the effect of reducing the boiler load and varying the baghouse operation. The second phase of testing was conducted from February 4, 1975, through February 14, 1975. The final phase, runs 22 through 31, which was designed to study the effect of operating with all new bags and varying the fuel mixture as in the first series of tests, was performed over the period from March 20, 1975, through March 29, 1975.

The inlet and outlet particulate mass concentrations determined by the total mass and cascade impactor sampling techniques are presented in Table 10. The particulate mass penetration and emission rate for each run are also presented in Table 10. The mass penetration was calculated from the inlet and outlet total mass concentrations, and the emission rate was calculated from the outlet total mass concentration and Sunbury S.E.S. logs and chart recordings data. The mass penetration and the total mass sample outlet concentration statistics for all the runs, runs 1 through 31, are presented in Table 11. These data show that the average particulate penetration and mean outlet concentration for the new bags were 1.7 times and 1.45 times greater, respectively, compared to the used fabric.

Table 10. RESULTS OF PARTICULATE SAMPLING AT SUNBURY STEAM ELECTRIC STATION

Run No.	Baghouse inlet concentration, grains/dscf				Baghouse outlet concentration, grains/dscf			Mass penetration,[a] percent	Emission rate, lbs/10^6 Btu
	Total mass sampler	Impactor run A	Impactor run B	Impactor run C	Total mass sampler	Impactor A	Impactor B		
1	3.6296	2.6154	-	-	0.0022	0.0046	0.0051	0.06	0.0047
2	2.6596	2.2244	1.3184	-	E	0.0272	0.0146	-	-
3	2.8082	2.0680	2.2677	-	E	0.0075	0.0084	-	-
4	4.1235	1.0839	3.5095	-	0.0013	0.0059	0.0064	0.03	0.0028
5	2.6851	2.5708	1.3776	-	0.0017	0.0028^D	0.0025^D	0.06	0.0039
6	2.5243	1.6296	2.8180	-	0.0014	0.0077	0.0060	0.06	0.0031
7	3.1661	2.0669	2.1190	-	0.0014	0.0029^D	P	0.04	0.0031
8	2.2977	2.5095	1.3616	-	0.0014	0.0024^D	0.0019^D	0.06	0.0031
9	2.4280	1.9984	1.9855	-	0.0015	0.0023^D	0.0029^D	0.06	0.0035
10	3.2936	2.0685	2.0120	-	0.0016	0.0014^D	S	0.05	0.0041
11	2.6678	2.5278	2.1174	-	0.0033	S	L^W	0.12	0.0101
12	2.0891	1.5471	2.0761	-	0.0017	0.0018^D	L^W	0.08	0.0044
13	2.6020	1.9184	2.5280	-	0.0020	0.0040^D	0.0010^W	0.08	0.0047
14	2.8845	1.4442	3.3717	-	0.0015	0.0018^D	0.0021^W	0.05	0.0035
15	2.6728	1.3356	1.3409	-	0.0016	S	0.0004^W	0.06	0.0037
16	2.4403	2.8056	1.0743	-	0.0013	S	0.0019^W	0.05	0.0033
17	2.5058	1.9631	1.9043	-	0.0016	0.0026^D	P^D	0.06	0.0038
18	1.8291	1.2430	2.0925	-	0.0013	0.0019^D	P^D	0.07	0.0031
19	2.8942	1.2809	1.9564	-	0.0016	0.0020^D	0.0002^W	0.06	0.0037
20	2.2016	1.3857	1.8968	-	0.0018	0.0024^D	P^D	0.08	0.0044
21	1.6694	2.2743	1.3782	-	0.0019	0.0032^D	0.0011^W	0.11	0.0044
22	1.3822	2.3328	1.7426	1.9390	0.0031	0.0016^W	0.0029^D	0.22	0.0074
23	3.2646	1.7175	1.4863	1.8851	0.0028	0.0014^W	0.0037^D	0.09	0.0063
24	2.0503	2.0914	2.2034	2.7331	0.0029	0.0015^W	0.0035^D	0.14	0.0058
25	3.0946	1.6760	1.6408	2.4440	0.0025	0.0019^W	0.0029^D	0.08	0.0056
26	2.3859	1.8363	1.8007	1.6942	0.0022	0.0033^W	0.0035^D	0.09	0.0047
27	1.3477	1.8289	1.8489	1.8929	0.0022	0.0002^W	0.0029^W	0.16	0.0051
28	3.0022	1.3270	1.8423	1.1209	0.0022	0.0009^W	0.0016^D	0.07	0.0049
29	2.0174	1.6922	1.8105	2.1041	0.0023	0.0012^W	0.0024^D	0.11	0.0054
30	2.0843	1.7849	1.9178	1.5965	0.0020	0.0010^W	0.0026^D	0.10	0.0044
31	2.2181	2.5772	2.3989	2.8530	0.0022	0.0011^W	0.0020^D	0.10	0.0047

[a] Calculated from the inlet and outlet total mass sampler concentrations.

NOTE: E = Excluded because of apparent vacuuming of the duct floor during sample collection.
D = Double substrates per stage.
P = Impactor with prefilter.
S = Substrates stuck together.
L = Substrates lost weight.
W = University of Washington Impactor.

Table 11. PENETRATION AND OUTLET CONCENTRATION

Runs	Penetration, percent		Outlet concentration, grains/dscf	
	Mean	Standard deviation	Mean	Standard deviation
All, normal and abnormal; new and used bags[a]	0.08276	0.03963	0.00195	0.00056
Normal with used bags[a]	0.06889	0.03018	0.00181	0.00063
Normal with new bags	0.11667	0.05610	0.00262	0.00038

[a] Does not include Runs no. 2 and no. 3 which were discounted because of apparent vacuuming of the outlet duct floor.

The inlet and outlet mass median diameters (mmd) for the inlet and outlet impactors for each run are listed in Table 12. The impactor A mmd values for runs 25 and 26 appear unreasonable; even though no traceable error has been found, it is suspected that the mmd values are excessively large. The inlet and outlet mmd statistical summaries for runs 1 through 31 are presented in Table 13. These data show that the mmd values for the filter effluents are, on the average, smaller than those for the inlet dust. Excluding the two questionable mmd values, the average outlet mmd was roughly 19 percent lower than that for the filter inlet.

The particle size distribution curves from which the mass mediam diameters were determined are presented in Appendix A. The differential size distribution curves for the inlet and outlet impactors for each run are presented in Appendix B. The differential size distribution curves, constructed in the manner described by Smith et al.,[10] were used to calculate the removal efficiency for six different size categories. The fractional efficiency curves are presented in Appendix C. The relationship between removal efficiency and particle size for used and new bags are graphed in

Table 12. PARTICLE SIZE MEASUREMENTS AT SUNBURY STEAM ELECTRIC STATION WITH ANDERSEN AND UNIVERSITY OF WASHINGTON CASCADE IMPACTORS

Run No.	Baghouse inlet mmd, μm			Baghouse outlet mmd, μm	
	Impactor run A	Impactor run B	Impactor run C	Impactor A	Impactor B
1	5.8	-	-	6.7	7.5
2	7.6	5.8	-	4.9	1.3
3	6.0	7.9	-	5.3	5.7
4	7.0	U	-	7.0	8.5
5	U	4.6	-	3.3^{D}	4.2^{D}
6	4.7	4.8	-	4.7	4.4
7	5.7	5.3	-	4.4^{D}	P
8	4.6	5.7	-	5.9^{D}	5.3^{D}
9	4.2	4.6	-	9.4^{D}	11.5^{D}
10	5.3	4.3	-	6.6^{D}	S
11	10.0	14.2	-	S	L^{W}
12	7.2	U	-	3.6^{D}	L^{W}
13	11.0	U	-	4.8^{D}	2.4^{W}
14	7.3	5.8	-	5.7^{D}	7.7^{W}
15	11.5	7.2	-	S	5.0^{W}
16	U	5.6	-	S	U^{W}
17	6.0	6.3	-	10.0^{D}	P^{D}
18	8.4	7.6	-	6.4^{W}	P^{D}
19	3.3	3.2	-	7.5^{D}	U^{W}
20	5.3	6.6	-	6.6^{D}	P^{D}
21	6.8	1.7	-	7.4^{D}	U^{W}
22	13.0	6.5	6.6	4.8^{W}	8.6^{D}
23	6.2	5.5	4.6	2.3^{W}	4.2^{D}
24	7.9	6.2	U	5.5^{W}	4.6^{D}
25	5.6	10.0	3.1	24.0$^{W\ R}$	1.4^{D}
26	10.0	12.0	7.4	22.0$^{W\ R}$	6.0^{D}
27	8.4	7.7	8.0	U^{W}	12.0^{D}
28	5.5	8.8	6.6	6.0^{W}	5.8^{D}
29	U	14.0	6.0	2.1^{W}	3.2^{D}
30	6.1	8.8	5.7	0.8^{W}	7.4^{D}
31	7.5	6.2	9.0	2.5^{W}	7.7^{D}

NOTE: U = Point unattainable.
D = Double substrates per stage.
P = Impactor with prefilter.
S = Substrates stuck together.
L = Substrates lost weight.
W = University of Washington impactor.
R = mmd seems unreasonable.

Figures 9 and 10. The impactor data show that the fractional efficiencies for the new bags are slightly higher than those for the used bags. This finding contradicts what would be expected based upon the higher mass efficiencies determined for the used bags. The difference might have been caused by the Andersen impactor substrate problems described previously. Furthermore, the shapes of the curves of Figures 9 and 10 are somewhat distorted for the larger particle sizes because of the use of the Andersen cyclone precollector at the baghouse inlet. The cyclone collects a significant number of particles in the 8 to 10 μm range that would ordinarily deposit on the upper impactor stages. This results in an incorrectly low estimate of removal efficiencies for the larger particles. Aside from the cascade impactor problem, however, it is believed that seepage and intermittent sloughing off of dust in the form of agglomerated particles may also constitute a significant fraction of the total effluent.

Table 13. INLET AND OUTLET MASS MEDIAN DIAMETERS

Runs	Inlet mmd, μm		Outlet mmd, μm	
	Mean	Standard deviation	Mean	Standard deviation
All, normal and abnormal; new and used bags	6.9	2.5	6.3, (5.6[a])	4.3, (2.5[a])
Normal with used bags	7.1	2.7	5.7	1.8
Normal with new bags	7.0	2.3	6.4, (4.9[b])	5.9, (2.2[b])

[a] Impactor A data for runs 25 and 26 excluded.

[b] Impactor A data for run 25 excluded.

A detailed listing of the condensation nuclei counter (CNC) measurements is presented in Appendix D. It was determined that the measurements made with the dilution system prior to the introduction of the in-stack diluter were inaccurate due to particles being generated in the sampling probe.

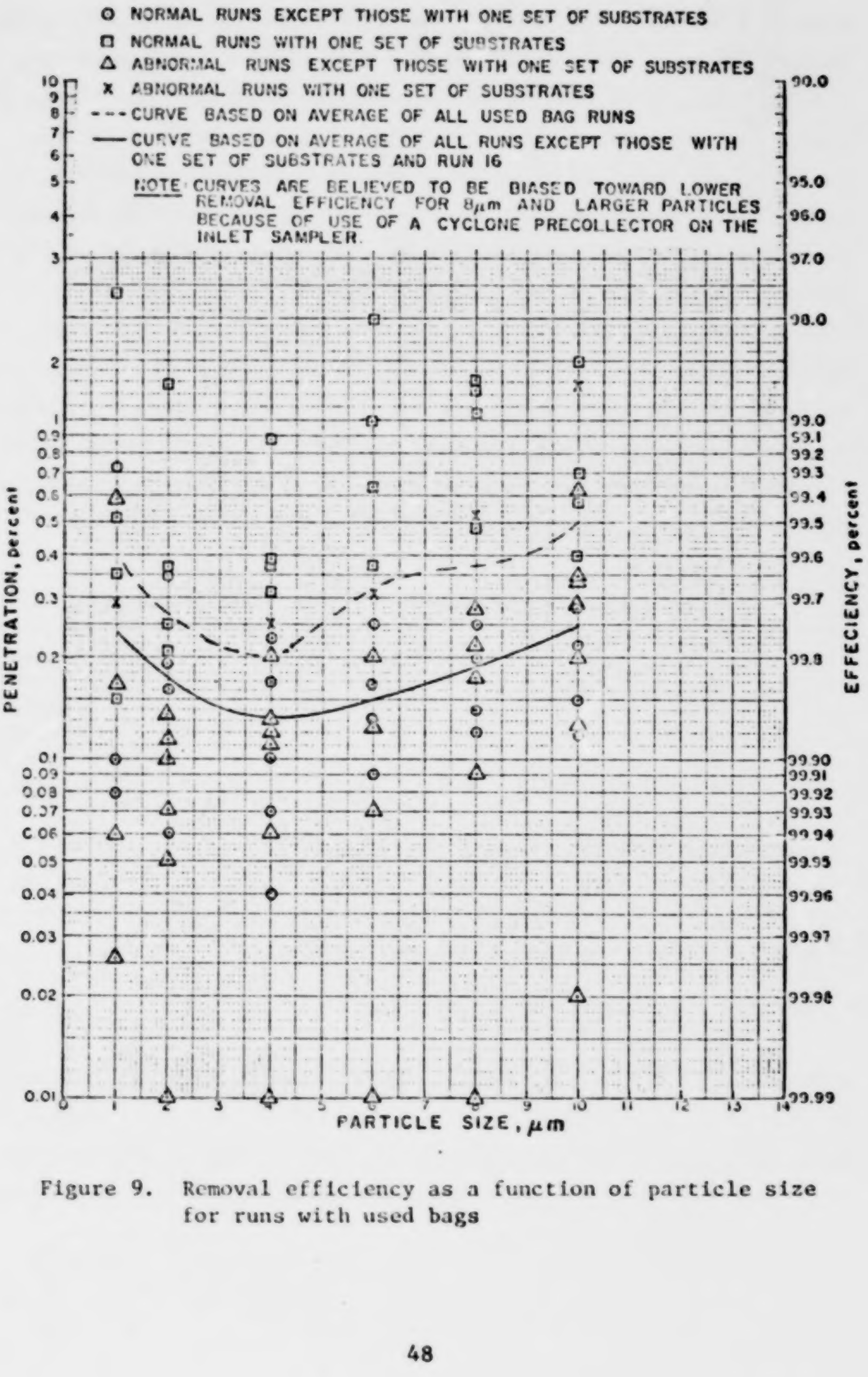


Figure 9. Removal efficiency as a function of particle size for runs with used bags

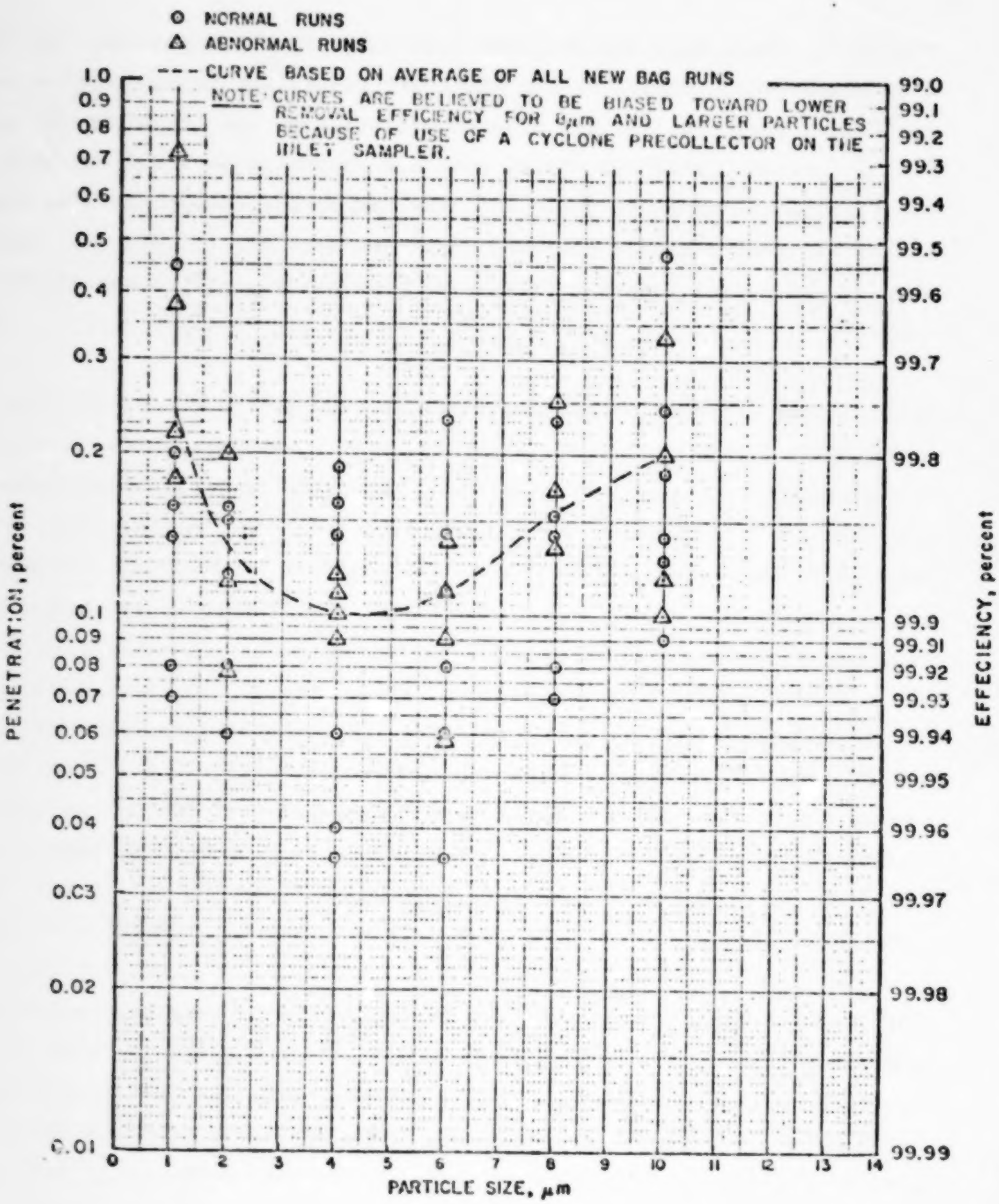


Figure 10. Removal efficiency as a function of particle size for runs with new bags

Therefore, these data are excluded from Table 14 which presents the CNC data summations. Copies of the CNC chart recordings (concentration versus real time) when the in-stack diluter was utilized are presented in Appendix E. Average inlet and outlet particle concentrations and estimates of penetration are given in Table 15. The CNC sizing measurements on the filter effluent indicate that the particles were all $\geq$ 0.015 μm. There were no successful baghouse inlet sizing measurements with the CNC/DD system.

Several other variables were monitored in addition to the particulate measurements. The monitored variables included fuel composition, boiler load and pressure drop across the baghouse. The fuel composition was determined for each run by analyzing daily samples of pulverized boiler feed, petroleum coke, anthracite silt and anthracite number 5 buckwheat. Complete fuel analyses are presented in Appendix F. The moisture, ash and sulfur contents of the pulverized feed ranged from 1.6 to 4.2 percent, 16.0 to 31.6 percent, and 1.2 to 3.2 percent, respectively. The average properties of the components of the pulverized feed are presented in Table 16. The boiler load was determined from the Sunbury Steam Electric Station chart recordings of the boiler steam flow which ranged from 360,000 to 410,000 lbs/hr for the full load runs. The pressure drop across the baghouse, which ranged from 2.0 to 3.6 "H_2O for the used bags and 0.4 to 0.7 "H_2O for the new bags, was also determined from the Sunbury chart recordings.

The averaged daily values of the pulverized feed properties, boiler load, and the pressure drop across the baghouse are summarized in Table 17. Although it was intended to regulate certain variables during each test, ideal control could not always be obtained. Table 18 presents the desired test characteristics for each run and the observed characteristics. In addition, the stack gases were monitored for oxygen, carbon dioxide, and sulfur dioxide by the Mobile Stack Gas Analyzer Trailer during several tests. These measurements are presented in Appendix H. Elemental analyses of selected coal and fly ash samples were made using atomic absorption (AA).

Table 14. SUMMARY OF CNC MEASUREMENTS MADE WITH IN-STACK DILUTER

Run no.	Time	Inlet concentration, particles/cc	Outlet concentration, particles/cc	DD flow, cc/sec
26	17:33		92,000	
	17:45		1,250,000	
	18:08		185,000	
	18:15		105,000	
27	10:45		88,000	
	11:00		124,000	
	11:15		153,000	
	11:30		124,000	
	11:45		114,000	
	12:00		116,000	
	12:10		93,000	
	12:15		74,000	
	12:25		91,000	
	12:33		67,000	
	12:45		42,000	
	13:00		74,000	
	13:13		54,000	
	13:30		96,000	
	13:45		93,000	
	14:00		71,000	
	14:15		87,000	
	14:23		47,000	
	14:41		69,000	
	15:00		85,000	50
28	11:30		2,500,000	
	11:45		2,300,000	
	12:00		520,000	
	12:15		258,000	

Table 14 (continued). SUMMARY OF CNC MEASUREMENTS MADE WITH IN-STACK DILUTER

Run no.	Time	Inlet concentration, particles/cc	Outlet concentration, particles/cc	DD flow, cc/sec
28	12:37		272,000	
	12:45		258,000	
	13:00		50,000	
	13:15		111,000	
	13:30		101,000	
	13:40		59,000	
	14:00		121,000	
	14:15		64,000	
	14:30		70,000	
	14:45		158,000	
	15:00		103,000	
	15:30		70,000	
	15:45		27,000	
	16:00		36,000	
	16:15		45,000	
	16:30		48,000	
	16:45		52,000	
	17:00		91,000	
29	12:30		37,000	
	12:45		49,000	
	13:00		62,000	
	13:15		62,000	
	13:30		55,000	
	13:45		66,000	
	14:00		62,000	
	14:15		66,000	
	14:30		58,000	
	14:45		54,000	

Table 14 (continued). SUMMARY OF CNC MEASUREMENTS MADE WITH IN-STACK DILUTER

Run no.	Time	Inlet concentration, particles/cc	Outlet concentration, particles/cc	DD flow, cc/sec
29	15:00		43,000	
	15:15		43,000	
	15:30		40,000	
	15:45		37,000	
	16:00		48,000	
30	10:45		40,000	
	11:00		65,000	
	11:15		80,000	
	11:30		83,000	
	11:45		86,000	
	12:00		90,000	
	12:15		100,000	
	12:30		100,000	
	12:55		97,000	
	14:30		80,000	
	14:45		72,000	
	15:00		62,000	
	15:10		71,000	
	15:25		98,000	50
	15:33		58,000	
	15:40		104,000	50
	16:17		126,000	
	16:28		116,000	50
	17:02		130,000	
	17:11		111,000	50
	17:15		111,000	
	17:18		93,000	50
	17:21		102,000	50

Table 14 (continued). SUMMARY OF CNC MEASUREMENTS MADE WITH IN-STACK DILUTER

Run no.	Time	Inlet concentration, particles/cc	Outlet concentration, particles/cc	DD flow, cc/sec
30	17:25		111,000	50
	17:28		111,000	50
	17:29		111,000	50
	17:37		111,000	50
	17:50		115,000	
31	12:04	9,500,000		
	12:30	7,600,000		
	12:55	6,700,000		
	13:10	5,600,000		
	13:24	3,400,000		
	13:40	3,600,000		
	13:55	6,200,000		
	14:10	5,600,000		
	14:25	5,800,000		
	14:35	6,600,000		
	14:48	5,500,000		
	15:05	3,800,000		

Table 15. AVERAGE INLET AND OUTLET PARTICLE CONCENTRATIONS MEASURED BY THE CNC

Run no.	Average inlet concentration, particles/cc	Average outlet concentration, particles/cc	Estimated penetration,[a] percent
26		408,000	7.0
27		88,000	1.5
28		332,000	5.7
29		52,000	0.9
30		88,000	1.5
31	5,800,000		

[a] Based on run no. 31 inlet concentration.

Table 16. THE AVERAGE PROPERTIES OF THE COMPONENTS OF THE PULVERIZED FEED

	As received		Dry basis									
	Total moisture, percent		Volatile matter, percent		Fixed carbon, percent		Ash, percent		Sulfur, percent		Heating value, Btu per pound	
Coal description	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Petroleum coke	7.0	1.7	12.0	1.1	87.0	1.4	1.0	1.4	4.8	0.9	15,296	339
Anthracite silt	17.7	1.5	7.4	0.6	61.2	4.4	31.4	4.6	0.6	0.2	9,776	769
Anthracite No. 5 buckwheat	13.7	2.2	7.8	0.8	72.1	3.0	20.1	3.1	0.7	0.3	11,728	557

Table 17. SUMMARY OF MONITORED VARIABLES

	Pulverized feed				
	As received	Dry basis			
Run no.	Moisture, %	Ash, %	Sulfur, %	Average boiler steam load, 1000 lbs/hr	Baghouse pressure drop, in. H_2O
1	2.9	18.5	2.1	400	2.8
2	3.1	19.8	2.3	405	2.8
3	4.2	23.6	1.7	410	2.7
4	3.1	25.1	1.7	395	2.6
5	3.0	23.6	1.6	400	2.8
6	2.6	21.1	2.2	410	2.8
7	3.4	31.6	1.8	410	2.7
8	2.9	29.5	1.5	400	2.7
9	3.2	22.6	2.2	400	2.6
10	3.0	23.0	1.4	370	2.6
11	2.5	19.7	2.2	360	2.3
12	2.1	16.0	3.2	325	2.4
13	2.6	18.8	1.6	325	2.0
14	1.7	18.7	1.7	310	2.0
15	3.0	22.2	1.3	390	2.7
16	2.7	20.6	1.2	390	2.7
17	3.2	23.5	1.6	375	2.7
18	2.4	19.0	1.5	400	2.7
19	2.8	21.6	1.5	400	3.6
20	2.6	22.2	1.2	380	3.5
21	1.8	21.7	1.4	375	2.8
22	2.3	20.7	2.1	370	0.4
23	3.5	22.3	1.8	380	0.5
24	3.6	22.6	1.8	410	0.6
25	4.1	20.6	2.4	380	0.6
26	3.5	23.2	1.6	400	0.6
27	2.7	18.3	2.1	400	0.7
28	3.2	21.1	2.1	410	0.7
29	3.6	23.8	1.6	370	0.7
30	2.7	23.1	1.5	390	0.7
31	3.3	22.0	2.0	400	0.7

Table 18. DESIRED AND OBSERVED PARAMETERS FOR EACH RUN

Run No.	Pulverized feed				Desired steam flow, 1000 lbs/hr	Observed steam flow, 1000 lbs/hr	Desired face velocity, ft/min	Observed face velocity, ft/min
	Desired ash, percent	Observed ash, percent	Desired sulfur, percent	Observed sulfur, percent				
1	24	18.5	1.7	2.1	400	400	2.05	2.02
2	24	19.8	1.7	2.3	400	410	2.05	2.11
3	24	23.6	1.7	1.7	400	400	2.05	2.03
4	24	25.1	1.7	1.7	400	395	2.05	2.07
5	20	23.6	2.4	1.6	400	400	2.05	2.18
6	20	21.1	2.4	2.2	400	410	2.05	2.21
7	24	31.6	1.7	1.8	400	410	2.05	2.03
8	26	29.5	1.4	1.5	400	400	2.05	2.05
9	26	22.6	1.4	2.2	400	400	2.05	2.07
10	24	23.0	1.7	1.4	400	370	2.05	2.08
11	24	19.7	1.7	2.2	400	360	2.05	1.88
12	24	16.0	1.7	3.2	400	325	2.05	1.82
13	24	18.8	1.7	1.6	300	325	2.05	1.69
14	24	18.7	1.7	1.7	300	310	2.05	1.64
15	24	22.2	1.7	1.3	400	390	2.05	2.05
16	24	20.6	1.7	1.2	400	390	2.05	2.05
17	24	23.5	1.7	1.6	400	375	2.05	1.95
18	24	19.0	1.7	1.5	400	400	2.05	2.07
19	24	21.6	1.7	1.5	400	400	2.42	2.45
20	24	22.2	1.7	1.2	400	380	2.42	2.36
21	24	21.7	1.7	1.4	400	375	2.05	2.01
22	24	20.7	1.7	2.1	400	370	2.05	2.10
23	24	22.3	1.7	1.8	400	330	2.05	2.02
24	24	22.6	1.7	1.8	400	410	2.05	1.96
25	24	20.6	1.7	2.4	400	380	2.05	2.01
26	20	23.2	2.4	1.6	400	400	2.05	2.05
27	20	18.3	2.4	2.1	400	400	2.05	2.22
28	24	21.1	1.7	2.1	400	410	2.05	2.15
29	26	23.8	1.4	1.6	400	370	2.05	1.95
30	26	23.1	1.4	1.5	400	390	2.05	1.99
31	24	22.0	1.7	2.0	400	400	2.05	2.05

The results of these analyses are presented in Table 19. Along with the AA analyses, some samples were examined by scanning electron microscopy and X-ray fluorescence. Photomicrographs at four magnifications of one fly ash sample are shown in Figures 11, 12, 13 and 14. The elemental analyses for the fly ash sample based upon X-ray fluorescence indicated Al, Si, S, K, Ti and Fe as primary components.

The effect of purposely altered variables was studied by performing two sample t-tests on the mean penetration and outlet concentration values for the normal runs versus each pair of abnormal runs for both the used bags and the new bags and for the normal runs with new bags versus the normal runs with used bags. These comparisons were made to determine if the null hypothesis that the means are equal would be accepted or rejected at the 0.10, 0.05, and 0.01 confidence levels. The designation of a run as normal or abnormal was based on the Sunbury Test Plan presented in Table 1, in which the normal runs were those with full boiler load, normal fuel mixture and normal baghouse operation.

The results of the t-tests are presented in Table 20. Table 20 shows that the effect of varying the fuel mixture, load, and baghouse operation had no statistically significant effect at the 0.10 level on either the outlet concentration or the penetration when the used bags were studied. However, varying the fuel mixture exerted a significant effect at the 0.10 level on the outlet concentration when the new bags were used. Significant differences in the outlet concentrations were also displayed at the 0.10, 0.05 and 0.01 levels and in the penetrations at the 0.10 and 0.05 levels when the normal runs for the new bags were compared with the normal runs for the used bags. The significant differences cited above are believed to be caused by the reduced fly ash holdings for the new bags as indicated by the lower pressure drop of 0.7 in. H_2O for the new bags as compared to 2.7 in. H_2O for the used bags.

Multiple regression analyses were used to identify which of the independent variables might (a) explain the variability in selected dependent

Table 19. ANALYSIS OF SELECTED COAL AND FLY ASH SAMPLES FROM BOILER NO. 1A

	Coal samples				Fly ash samples			
	3/22/75	3/24/75	3/26/75	3/28/75	3/22/75	3/24/75	3/26/75	3/28/75
% Ash	22.65	21.83	21.15	22.14	-	-	-	-
Ash analysis								
% Loss on ignition	-	-	-	-	3.89	5.27	4.17	2.69
% Moisture	-	-	-	-	0.39	0.50	0.12	0.17
% Silica (SiO_2)	54.75	57.65	55.80	57.30	47.91	44.62	45.22	47.60
% Iron oxide (Fe_2O_3)	18.77	17.29	18.79	17.29	26.76	28.70	28.91	28.27
% Aluminum oxide (Al_2O_3)	19.29	18.52	18.72	18.52	18.95	18.66	18.95	19.23
% Calcium oxide (CaO)	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
% Titanium oxide (TiO_2)	1.19	1.19	1.19	1.19	1.43	1.40	1.29	1.31
% Potassium oxide (K_2O)	0.94	0.98	0.80	0.78	0.12	0.16	0.11	0.11
% Sodium oxide (Na_2O)	0.15	0.14	0.16	0.14	0.05	0.05	0.05	0.05

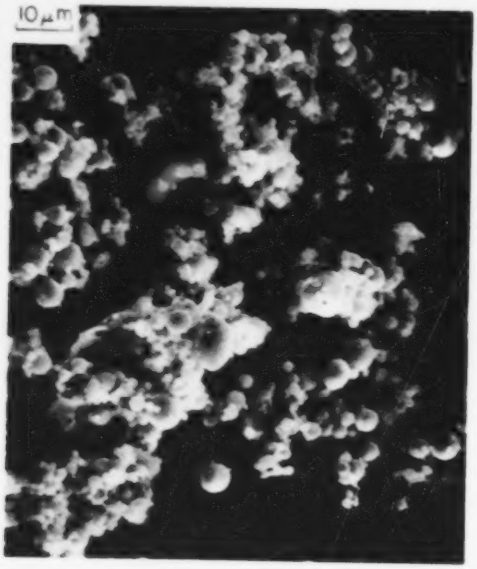


Figure 11. Fly ash from 1-A baghouse hopper number 2, March 26, 1975; scanning electron micrograph; 1000 magnification at 20 kV

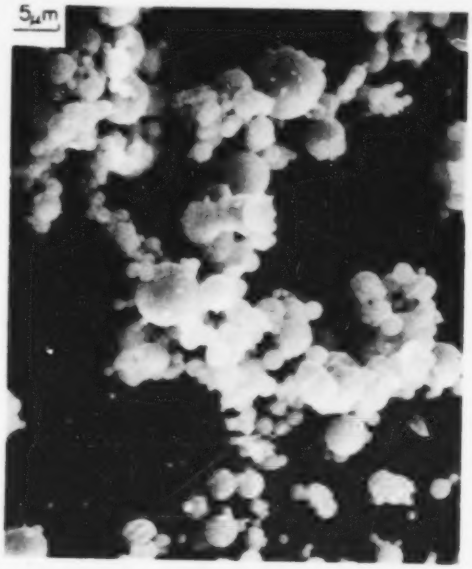


Figure 12. Fly ash from 1-A baghouse hopper number 2, March 26, 1975; scanning electron micrograph; 2000 magnification at 20 kV

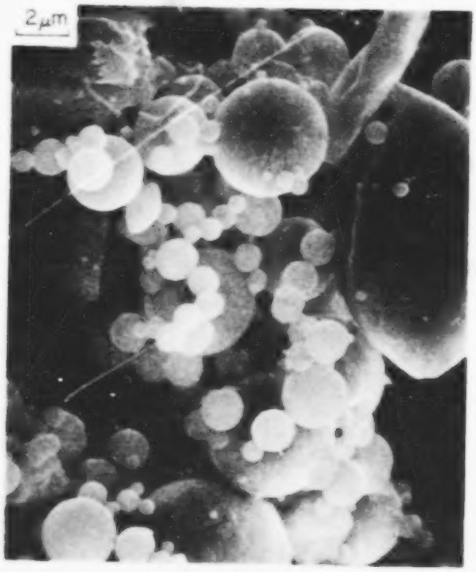


Figure 13. Fly ash from 1-A baghouse hopper number 2, March 26, 1975; scanning electron micrograph; 5000 magnification at 20 kV

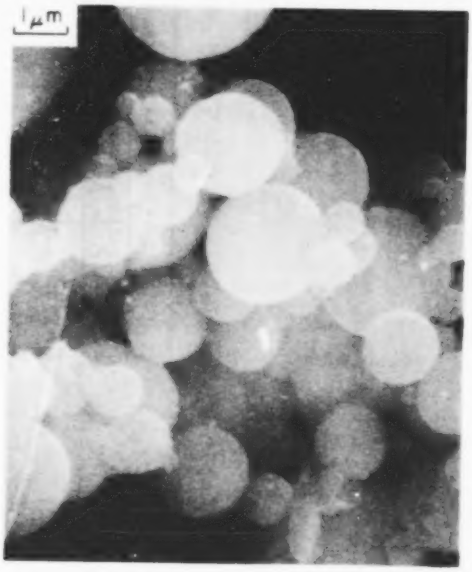


Figure 14. Fly ash from 1-A baghouse hopper number 2, March 26, 1975; scanning electron micrograph; 10,000 magnification at 20 kV

Table 20. RESULTS OF t-tests

Description of type of run of sample 1	Description of type of run of sample 2	Accept or reject the null hypothesis that the sample 1 and sample 2 means are equal					
		Outlet concentration			Penetration		
		At 0.10 level	At 0.05 level	At 0.01 level	At 0.10 level	At 0.05 level	At 0.01 level
Normal runs[a] with used bags[b]	Type A[c] abnormal runs with used bags	accept	accept	accept	accept	accept	accept
Normal runs with used bags[b]	Type B[d] abnormal runs with used bags	accept	accept	accept	accept	accept	accept
Normal runs with used bags[b]	Type C[e] abnormal runs with used bags	accept	accept	accept	accept	accept	accept
Normal runs with used bags[b]	Type D[f] abnormal runs with used bags	accept	accept	accept	accept	accept	accept
Normal runs with used bags[b]	Type E[g] abnormal runs with used bags	accept	accept	accept	accept	accept	accept
Normal runs with new bags	Type A abnormal runs with new bags	reject	accept	accept	accept	accept	accept
Normal runs with new bags	Type B abnormal runs with new bags	reject	accept	accept	accept	accept	accept
Normal runs with new bags	Normal runs with used bags[b]	reject	reject	reject	reject	reject	accept

[a] Normal runs were those runs in which no parameters were purposely varied.

[b] Does not include runs 2 and 3 because of suspected vacuuming of the duct floor on the outlet.

[c] Type A abnormal runs were those runs designed to have a fuel mixture containing maximum sulfur and minimum ash.

[d] Type B abnormal runs were those runs designed to have a fuel mixture containing maximum ash and minimum sulfur.

[e] Type C abnormal runs were those runs at reduced load (approximately 3/4 designed load).

[f] Type D abnormal runs were those runs during which there was 1/2 hour between cleaning cycles. Normally, when one cleaning cycle would end, the next would begin.

[g] Type E abnormal runs were those runs during which two of the fourteen compartments were taken out of service.

variables and (b) indicate to what extent each of the measured independent variables might explain the variability. The dependent variables selected were the baghouse particulate penetration, the baghouse outlet particulate concentration and the mass median diameter of the particles in the baghouse effluent. The regression analyses were made on the series of normal runs with the used bags, the normal runs with the new bags, and on all the runs. Runs 2 and 3 were excluded from all analyses because of suspected pick up of dust from the duct floor due to sampling nozzle proximity. The values of the dependent and independent variables used in the regression analysis for each series of runs are presented in Tables 21, 22, and 23. The list of variables analyzed and their contributions toward explaining the variation in the dependent variables are presented in Table 24.

Table 24 shows that for the complete series of tests (Case 1) most of the variability in penetration is explained by the inlet concentration (48.58 percent), most of the variability of the outlet concentration is explained by the baghouse pressure drop (45.55 percent) and most of the variability of the outlet mmd is explained by the number of compartments in use (9.93 percent).

For the series of normal runs with the used bags (Case 2) 99.45 percent of the variation in penetration is explained by the moisture content of the fuel (63.04 percent), sulfur content of the fuel (11.89 percent), inlet mass median diameter (mmd) (7.90 percent), ash content (3.80 percent) and face velocity (2.12 percent).

For the normal runs with the used bags, most of the variability of the penetration is explained by the moisture content (63.40 percent), most of the variability of the outlet concentration is explained by the face velocity (32.26 percent) and most of the variability of the outlet mmd is also explained by the face velocity (56.31 percent).

For the normal runs with the new bags (Case 3) most of the variability of the penetration is explained by the inlet concentration (81.60 percent),

Table 21. VALUES OF THE CASE 1[a] VARIABLES USED IN THE MULTIPLE REGRESSION ANALYSIS

Run No.	Inlet concentration, gr/dscf	Outlet concentration, gr/dscf	Penetration, %	Inlet mmd, μm	Outlet mmd, μm	Fuel moisture, %	Fuel ash, %	Fuel sulfur, %	Steam flow, 1000 lbs/hr	Face velocity, ft/min	Baghouse pressure drop, "H_2O	Compartments cleaned per hour
1	3.6296	0.0022	0.06	5.8	7.1	2.9	18.5	2.1	400	2.02	2.6	28
4	4.1235	0.0013	0.03	7.0	7.7	3.1	25.1	1.7	395	2.07	2.6	28
5	2.6851	0.0017	0.06	4.6	3.7	3.0	23.6	1.6	400	2.18	2.8	28
6	2.5243	0.0014	0.06	4.7	4.5	2.6	21.1	2.2	410	2.21	2.8	28
7	3.1661	0.0014	0.04	5.5	4.4	3.4	31.6	1.8	410	2.03	2.7	28
8	2.2977	0.0014	0.06	5.1	5.6	2.9	29.5	1.5	400	2.05	2.7	28
9	2.4280	0.0015	0.06	4.4	10.4	3.2	22.6	2.2	400	2.07	2.6	28
10	3.2926	0.0016	0.05	4.8	6.6	3.0	23.0	1.4	370	2.08	2.6	28
11	2.6678	0.0033	0.12	11.9	6.1	2.5	19.7	2.2	360	1.88	2.3	28
12	2.0891	0.0017	0.08	7.2	3.6	2.1	16.0	3.2	325	1.82	2.4	28
13	2.6020	0.0020	0.08	11.0	3.4	2.6	18.8	1.6	375	1.69	2.0	28
14	2.8845	0.0015	0.05	6.5	6.6	1.7	18.7	1.7	310	1.64	2.0	28
15	2.6728	0.0016	0.06	9.1	5.0	3.0	22.2	1.3	390	2.05	2.7	28
16	2.4403	0.0013	0.05	5.6	6.1	2.7	20.6	1.2	390	2.05	2.7	14
17	2.5058	0.0016	0.06	6.1	10.0	3.2	23.5	1.6	375	1.98	2.7	24
18	1.8291	0.0013	0.07	8.0	6.4	2.4	19.0	1.5	400	2.07	2.7	28
19	2.8942	0.0016	0.06	3.2	7.5	2.8	21.6	1.5	400	2.45	3.6	28
20	2.7016	0.0018	0.08	5.9	6.6	2.6	22.2	1.2	380	2.36	3.5	28
21	1.6694	0.0019	0.11	3.4	7.4	1.8	21.7	1.4	375	2.01	2.8	28
22	1.3822	0.0031	0.22	8.2	6.4	2.3	20.7	2.1	370	2.10	0.4	28
23	3.2646	0.0028	0.09	5.4	3.1	3.5	22.3	1.8	380	2.02	0.5	28
24	2.0503	0.0029	0.14	7.0	5.0	3.6	22.6	1.8	410	1.96	0.5	28
25	3.0946	0.0025	0.08	5.6	5.8	4.1	20.6	2.4	380	2.01	0.6	28
26	2.3359	0.0022	0.09	9.6	11.5	3.5	23.2	1.6	400	2.05	0.6	28
27	1.3477	0.0022	0.16	8.0	12.0	2.7	18.3	2.1	400	2.22	0.7	28
28	3.0022	0.0022	0.07	6.8	5.9	3.2	21.1	2.1	410	2.15	0.7	28
29	2.0174	0.0023	0.11	9.2	2.6	3.6	23.8	1.6	370	1.95	0.7	28
30	2.0843	0.0020	0.10	6.7	2.4	2.7	23.1	1.5	390	1.99	0.7	28
31	2.2181	0.0022	0.10	7.5	4.4	3.3	22.0	2.0	400	2.05	0.7	28
Mean	2.5328	0.0020	0.08	6.4	6.1	2.9	22.0	1.8	384	2.04	2.0	27.0
Standard deviation	0.6346	0.0006	0.04	1.4	2.5	0.5	3.1	0.4	26	0.16	1.0	3.6

[a] Case 1 is the entire series of tests including the normal and abnormal runs with the new and used bags, except runs 2 and 3 which were discounted because of suspected vacuuming of the outlet duct floor during sampling.

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Table 22. VALUES OF THE CASE 2[a] VARIABLES USED IN THE MULTIPLE REGRESSION ANALYSIS

Run No.	Inlet concentration, gr/dscf	Outlet concentration, gr/dscf	Penetration, %	Inlet mmd, µm	Outlet mmd, µm	Fuel moisture, %	Fuel ash, %	Fuel sulfur, %	Steam flow, 1000 lbs/hr	Face velocity, ft/min	Baghouse pressure drop, "H_2O	Compartments cleaned per hour
1	3.6296	0.0022	0.06	5.8	7.1	2.9	18.5	2.1	400	2.02	2.8	28
4	4.1235	0.0013	0.03	7.0	7.7	3.1	25.1	1.7	395	2.07	2.6	28
7	3.1661	0.0014	0.04	5.5	4.4	3.4	31.6	1.8	410	2.03	2.7	28
10	3.2926	0.0016	0.05	4.8	6.6	3.0	23.0	1.4	370	2.08	2.6	28
11	2.6678	0.0033	0.12	11.9	6.1	2.5	19.7	2.2	360	1.88	2.3	28
12	2.0591	0.0017	0.08	7.2	3.6	2.1	16.0	3.2	325	1.82	2.4	28
15	2.6728	0.0016	0.06	9.1	5.0	3.0	22.0	1.3	390	2.05	2.7	28
18	1.8271	0.0013	0.07	[illegible]	6.4	2.4	19.0	1.5	400	2.07	2.7	28
21	1.6694	0.0019	0.11	3.4	7.4	1.8	21.7	1.4	375	2.01	2.8	28
Mean	2.7933	0.0018	0.07	7.0	6.0	2.7	21.9	1.8	380	2.00	2.6	28
Standard deviation	0.8349	0.0006	0.03	2.5	1.4	0.5	4.5	0.6	26	0.09	0.2	0

[a] Case 2 is the series of normal runs with the used bags, except runs 2 and 3 which were discounted because of suspected vacuuming of the outlet duct floor during sampling.

Table 23. VALUES OF THE CASE 3[a] VARIABLES USED IN THE MULTIPLE REGRESSION ANALYSIS

Run No.	Inlet concentration, gr/dscf	Outlet concentration, gr/dscf	Penetration, %	Inlet mmd, µm	Outlet mmd, µm	Fuel moisture, %	Fuel ash, %	Fuel sulfur, %	Steam flow, 1000 lbs/hr	Face velocity, ft/min	Baghouse pressure drop, "H_2O	Compartments cleaned per hour
22	1.3822	0.0031	0.22	8.2	6.4	2.3	20.7	2.1	370	2.10	0.4	28
23	3.2646	0.0028	0.09	5.4	3.1	3.5	22.3	1.8	380	2.02	0.5	28
24	2.0503	0.0029	0.14	7.0	5.0	3.6	22.6	1.8	410	1.96	0.6	28
25	3.0946	0.0025	0.08	5.6	5.8	4.1	20.6	2.4	380	2.01	0.6	28
28	3.0022	0.0022	0.07	6.8	5.9	3.2	21.1	2.1	410	2.15	0.7	28
31	2.2181	0.0022	0.10	7.5	4.4	3.3	22.0	2.0	400	2.05	0.7	28
Mean	2.5020	0.0026	0.12	6.8	5.1	3.3	21.5	2.0	392	2.05	0.6	28
Standard deviation	0.7378	0.0004	0.06	1.1	1.2	0.6	0.8	0.2	17	0.07	0.1	0

[a] Case 3 is the series of normal runs with the new bags.

Table 24. RESULTS OF MULTIPLE REGRESSION ANALYSES

Variable	Variability of the dependent variable explained by the independent variable, percent								
	Case 1[a]			Case 2[b]			Case 3[c]		
	Penetration	Outlet concentration	Outlet mmd	Penetration	Outlet concentration	Outlet mmd	Penetration	Outlet concentration	Outlet mmd
Inlet concentration	48.58	< 1	< 1	< 1	17.43	16.50	81.60	< 1	< 1
Inlet mass median diameter (mmd)	< 1	< 1	1.76	7.90	5.37	9.84	< 1	< 1	40.41
Moisture content of fuel	1.56	< 1	2.49	63.40	< 1	2.41	< 1	< 1	2.65
Ash content of fuel	< 1	3.14	< 1	3.80	9.39	< 1	< 1	< 1	56.45
Sulfur content of fuel	< 1	< 1	< 1	11.89	16.76	6.58	< 1	1.04	< 1
Steam flow	< 1	< 1	3.43	4.54	10.37	6.08	< 1	11.89	< 1
Face velocity	2.68	< 1	5.75	2.12	32.26	56.31	< 1	5.68	< 1
Number of compartments cleaned per hour	< 1	< 1	9.93	same for all runs	same for all runs	same for all runs	same for all runs	same for all runs	same for all runs
Baghouse pressure drop	20.51	45.55	< 1	5.50	7.73	1.98	17.75	81.27	< 1

[a] Case 1 is the entire series of tests including the normal and abnormal runs with the new and used bags, except runs 2 and 3 which were discounted because of suspected vacuuming of the outlet duct floor during sampling.

[b] Case 2 is the series of normal runs with the used bags, except runs 2 and 3 which were discounted because of suspected vacuuming of the outlet duct floor during sampling.

[c] **Case 3 is the series of normal runs with the new bags.**

most of the variability of the outlet concentration is explained by the baghouse pressure drop (81.27 percent) and most of the variability of the outlet mmd is explained by the ash content of the pulverized boiler feed (56.45 percent).

The multiple regression analysis also calculated the constant and the coefficients of the independent variables for the line of best fit through the data points. Equations (1), (2), and (3) were constructed for all the runs except runs 2 and 3 and include normal and abnormal conditions for the new and used bags. Runs 2 and 3 were omitted because of suspected vacuuming of the duct floor during sampling. The standard error of each coefficient has been included to show the variability and, therefore, indicate the precision of the coefficient.

Equation (1) explains 73.33 percent of the variations in the penetrations.

$$\begin{aligned}\text{penetration } (\%) = {} & 0.1607 \\ & - (0.0270 \pm 0.0083)(\text{inlet concentration, grains/dscf}) \\ & - (0.0186 \pm 0.0107)(\text{moisture, }\%) \\ & + (0.0455 \pm 0.0293)(\text{face velocity, ft/min}) \\ & - (0.0246 \pm 0.0055)(\text{baghouse pressure drop, }{''}H_2O). \qquad (1)\end{aligned}$$

Equation (2) explains 48.69 percent of the variations in the outlet concentrations.

$$\begin{aligned}\text{concentration (grains/dscf)} = {} & 0.00333 \\ & - (0.00003 \pm 0.00003)(\text{ash, }\%) \\ & - (0.00035 \pm 0.00008)(\text{baghouse pressure drop, }{''}H_2O). \qquad (2)\end{aligned}$$

Equation (3) explains 23.36 percent of the variations in the outlet mass median diameters.

$$\begin{aligned}\text{mass median diameters } (\mu\text{m}) = {} & 3.7163\\ & - (0.1405 \pm 0.1933)(\text{inlet mmd, } \mu\text{m})\\ & - (0.7548 \pm 0.6175)(\text{moisture, }\%)\\ & + (0.0171 \pm 0.0180)(\text{steam flow, 1000 lbs/hr})\\ & + (0.2406 \pm 2.5765)(\text{face velocity, ft/min})\\ & - (0.1483 \pm 0.0782)(\text{number of compartments cleaned per hour}). \qquad (3)\end{aligned}$$

Equations (4), (5), and (6) are constructed from all the runs except runs 2 and 3 with the system operating normally using the used bags.

Equation (4) explains 99.5 percent of the variations in the penetrations.

$$\begin{aligned}\text{penetration } (\%) = {} & 1.2093\\ & - (0.0053 \pm 0.0024)(\text{inlet mmd, } \mu\text{m})\\ & - (0.0250 \pm 0.0111)(\text{moisture, }\%)\\ & - (0.0021 \pm 0.0010)(\text{ash, }\%)\\ & - (0.0525 \pm 0.0125)(\text{sulfur, }\%)\\ & + (0.0007 \pm 0.0003)(\text{steam flow, 1000 lbs/hr})\\ & - (0.4727 \pm 0.1080)(\text{face velocity, ft/min})\\ & - (0.0907 \pm 0.0474)(\text{baghouse pressure drop, }"H_2O). \qquad (4)\end{aligned}$$

Equation (5) explains 99.32 percent of the variations in the outlet concentrations.

$$\begin{aligned}\text{concentration (grains/dscf)} = {} & 0.03700\\ & + (0.00052 \pm 0.00010)(\text{inlet concentration, grains/dscf})\\ & - (0.00019 \pm 0.00004)(\text{inlet mmd, } \mu\text{m})\\ & - (0.00010 \pm 0.00002)(\text{ash, }\%)\\ & - (0.00165 \pm 0.00024)(\text{sulfur, }\%)\\ & + (0.00002 \pm 0.00000)(\text{steam flow, 1000 lbs/hr})\\ & - (0.01611 \pm 0.00204)(\text{face velocity, ft/min})\\ & - (0.00283 \pm 0.00084)(\text{baghouse pressure drop, }"H_2O). \qquad (5)\end{aligned}$$

Equation (6) explains 99.70 percent of the variations in the outlet mass median diameters.

$$\begin{aligned}\text{mass median diameter } (\mu\text{m}) = {} & 0.8982 \\ & + (1.1320 \pm 0.1227)(\text{inlet concentration, grains/dscf}) \\ & - (0.2498 \pm 0.0433)(\text{inlet mmd, } \mu\text{m}) \\ & - (2.3952 \pm 0.2316)(\text{moisture, \%}) \\ & - (0.4629 \pm 0.2439)(\text{sulfur, \%}) \\ & + (0.0368 \pm 0.0050)(\text{steam flow, 1000 lbs/hr}) \\ & + (5.2412 \pm 2.1313)(\text{face velocity, ft/min}) \\ & - (5.3960 \pm 0.9032)(\text{baghouse pressure drop, "}H_2O). \end{aligned} \tag{6}$$

Equations (7), (8), and (9) are constructed for the runs with the system operating normally using the new bags.

Equation (7) explains 99.35 percent of the variations in the penetrations.

$$\begin{aligned}\text{penetration } (\%) = {} & 0.3825 \\ & - (0.0550 \pm 0.0038)(\text{inlet concentration, grains/dscf}) \\ & - (0.2200 \pm 0.0243)(\text{baghouse pressure drop, "}H_2O). \end{aligned} \tag{7}$$

Equation (8) explains 99.88 percent of the variations in the outlet concentrations.

$$\begin{aligned}\text{concentration (grains/dscf)} = {} & 0.00188 \\ & + (0.00025 \pm 0.00000)(\text{sulfur, \%}) \\ & + (0.00002 \pm 0.00000)(\text{steam flow, 1000 lbs/hr}) \\ & - (0.00151 \pm 0.00000)(\text{face velocity, ft/min}) \\ & - (0.00475 \pm 0.00000)(\text{baghouse pressure drop, "}H_2O). \end{aligned} \tag{8}$$

Equation (9) explains 99.51 percent of the variations in the outlet mass median diameters.

$$\begin{aligned}\text{mass median diameter } (\mu\text{m}) &= 10.6406\\ &+ (0.6543 \pm 0.0600)(\text{inlet mmd, } \mu\text{m})\\ &+ (0.2518 \pm 0.0763)(\text{moisture, \%})\\ &- (0.5415 \pm 0.0355)(\text{ash, \%}).\end{aligned} \tag{9}$$

When using the numbers generated by the multiple regression analysis, several factors should be considered. First, although the statistical analyses were made on a substantial number of data sets — 29 for Case 1, 9 for Case 2, and 6 for Case 3 — the above quantities are minimal for statistical analysis. Accordingly, the greatest confidence in the results of the analyses is placed on Case 1, because it has the most data sets. Second, the extent to which the independent variables could be changed was limited because of the nature of the installation tested. Therefore, the range over which parameters were varied should be kept in mind when using the results of the analysis to predict what might occur in another system. Third, the analytical procedure is designed so that, when two or more of the independent variables explain the same variability of a dependent variable, the procedure will select only one of the variables to which to attribute all of the common influence, thereby overshadowing the other variable(s). Finally, the accuracy of the mmd values used in the analyses is somewhat questionable because of the impactor problems described previously in Section V.

The multiple regression analyses produced the expected results in most cases. Table 24 shows, for Cases 1 and 3, a strong dependency of penetration and outlet concentration on baghouse pressure drop; and Equations (1), (2), (7), and (8) predict a decrease in penetration and outlet concentration for an increase in baghouse pressure drop. It has been documented that penetration and outlet concentration decrease as fabric filter pressure drop increases when the increase in baghouse pressure is caused by an increased cloth loading.[11,12] At Sunbury, the major differences in cloth loadings were due to renewal of the 2-year-old bags.

Table 24 also shows, for Cases 1 and 3, a strong dependency of penetration on inlet concentration, but no dependency of outlet concentration on inlet concentration; and Equations (1) and (7) predict a decrease in penetration for an increase in inlet concentration. These relationships support previous studies which showed that the outlet concentration is relatively unaffected by the inlet concentration.[13] For Case 1, the relatively small effects attributed to the independent variables in explaining the outlet mmd's indicates that they are only slightly affected by the changes made. In Case 3, however, the strong dependence of outlet mmd's on the inlet mmd seems reasonable because, when the new bags had very little cloth loading, some of the inlet particles may have been able to pass through the fabric. This is supported by Equation (9) which predicts an increase in outlet mmd for an increase in inlet mmd. In Case 2, the high dependency of penetration on the moisture content of the fuel and the lack of dependency on the inlet concentration is difficult to explain. When the penetration is plotted against the inlet concentration and moisture content of the fuel for Case 2, two very similar curves result. It is, therefore, theorized that the moisture content of the fuel overshadowed the effect of the inlet concentration, causing the analysis to give unexpected results. Also, in Case 2, the high dependencies of outlet concentration and outlet mmd on face velocity were unexpected, and since the strong dependence is not evident in Case 1, it is thought to be due to coincidence rather than a real effect. The strong dependence of outlet mmd on ash content of the fuel is also believed to be caused by coincidence because of the absence of dependency in Case 1.

SECTION VII

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APPENDIX A

PARTICLE SIZE DISTRIBUTION CURVES

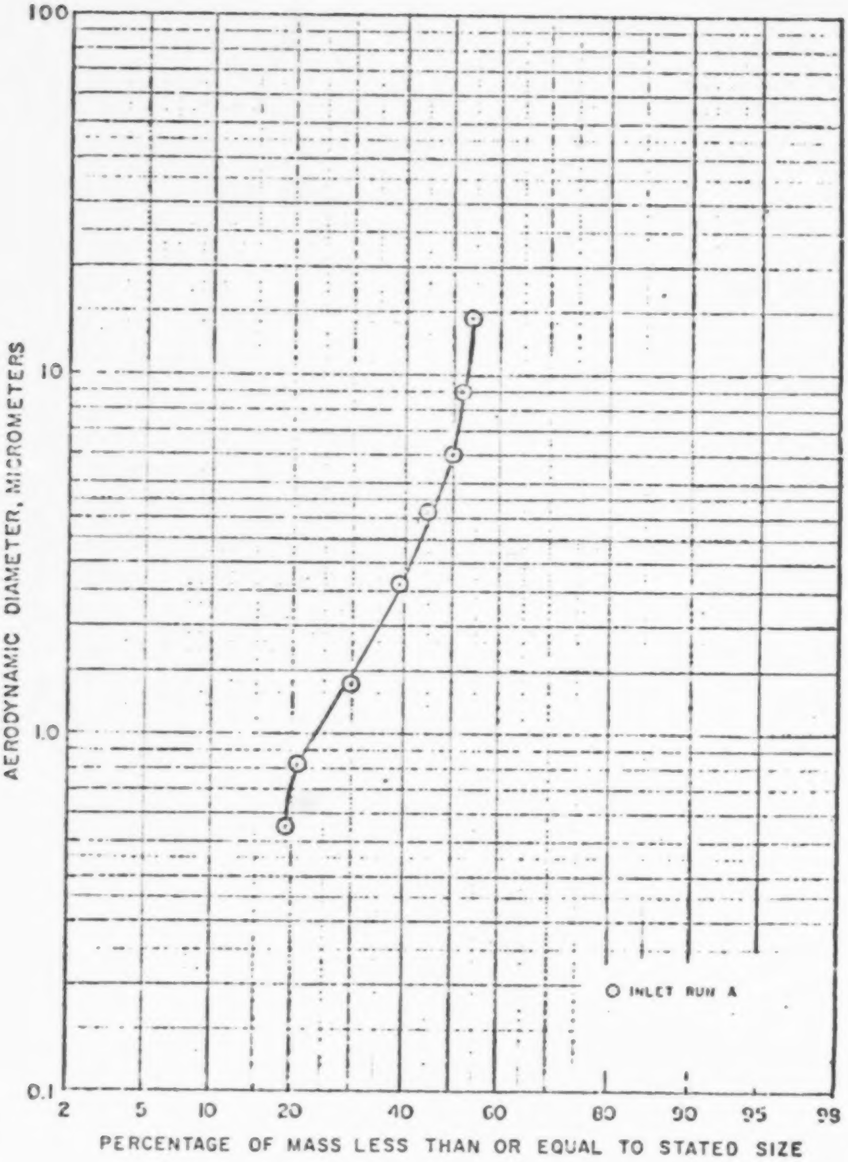


Figure 15. Inlet cumulative particle size distribution for run 1

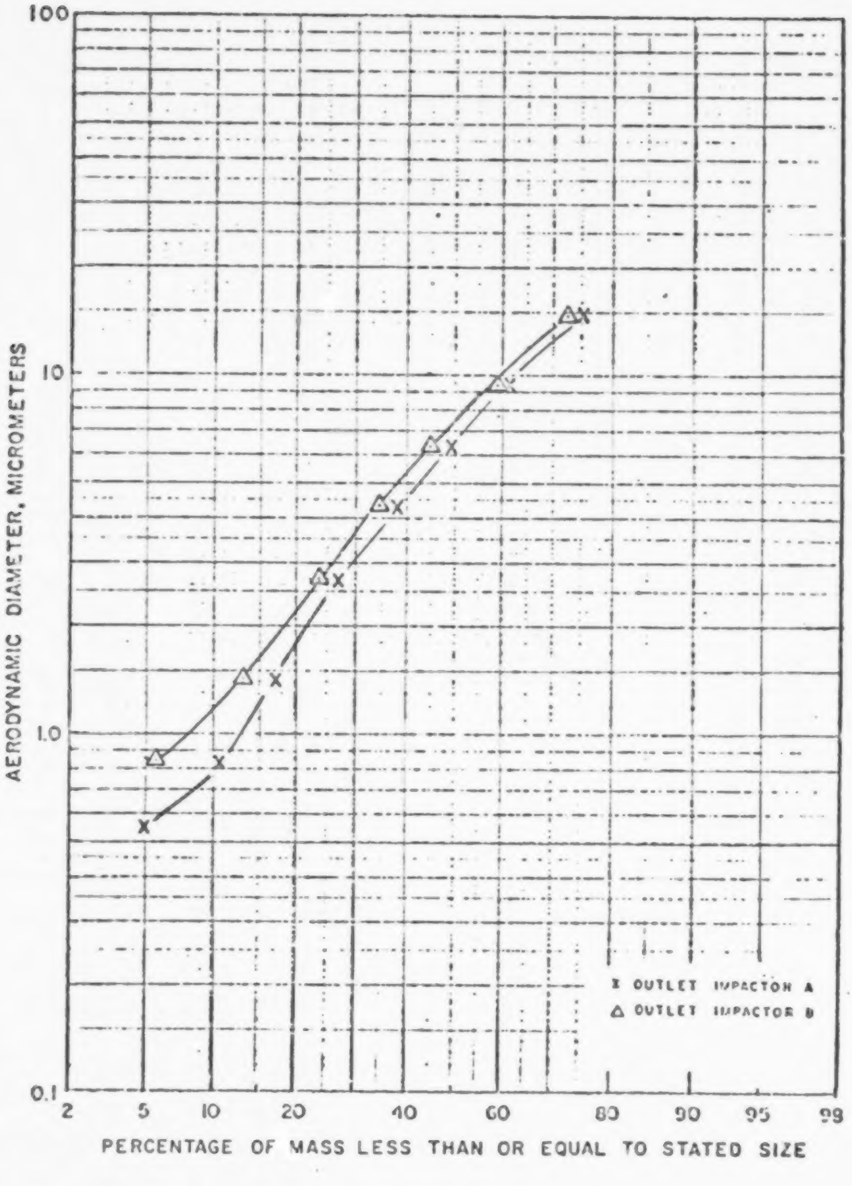


Figure 16. Outlet cumulative particle size distribution for run 1

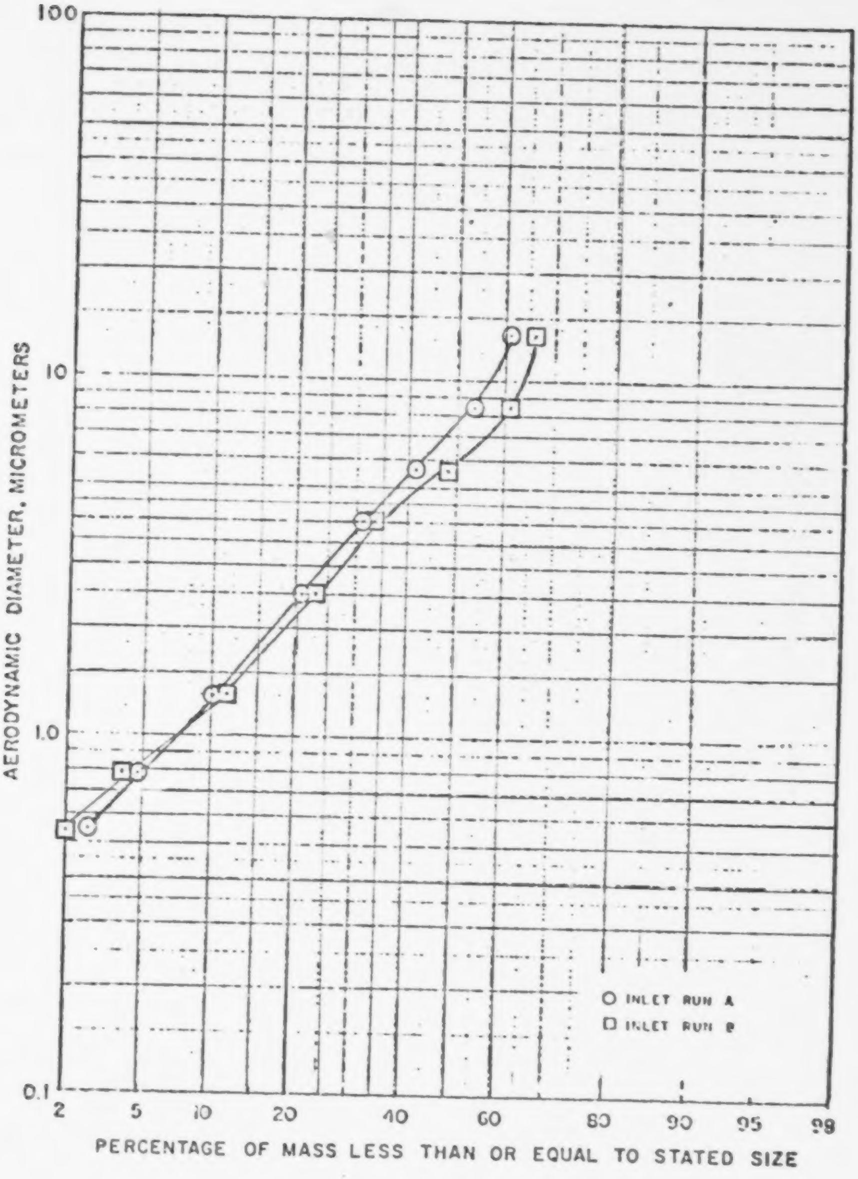


Figure 17. Inlet cumulative particle size distribution for run 2

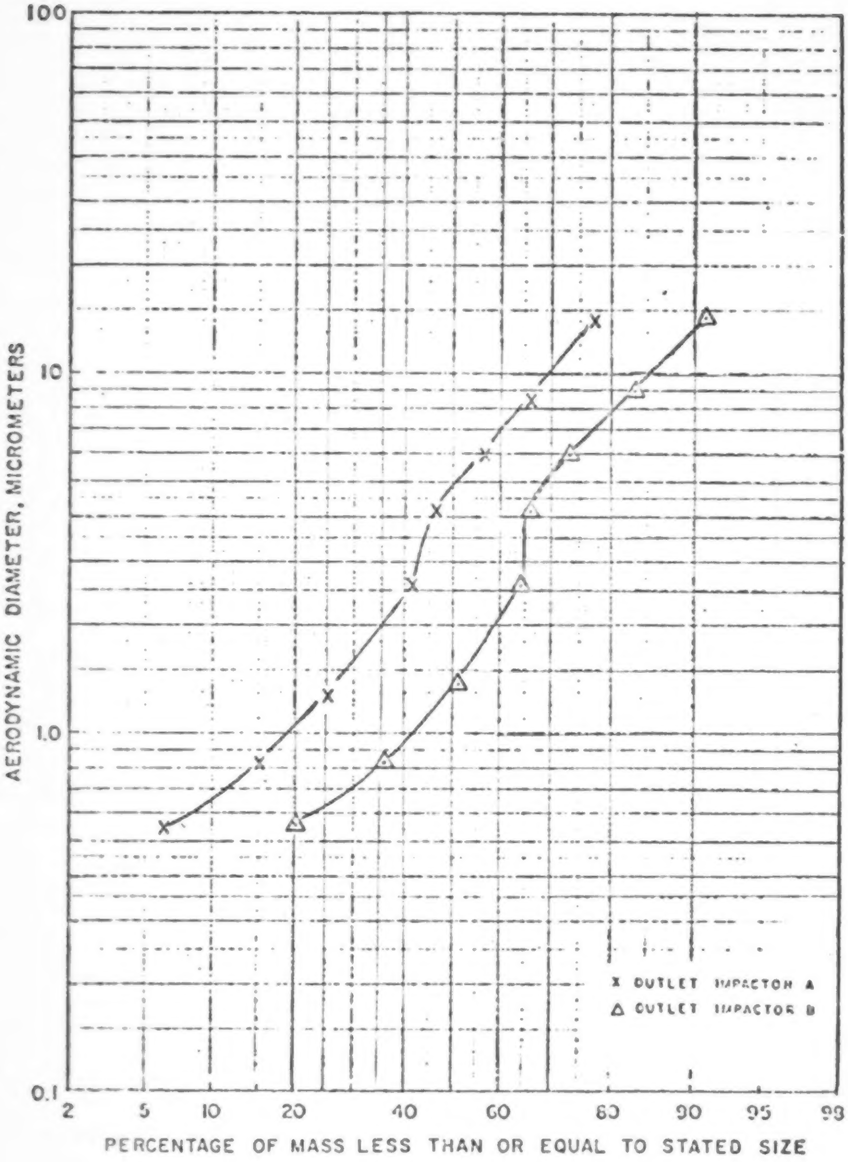


Figure 18. Outlet cumulative particle size distribution for run 2

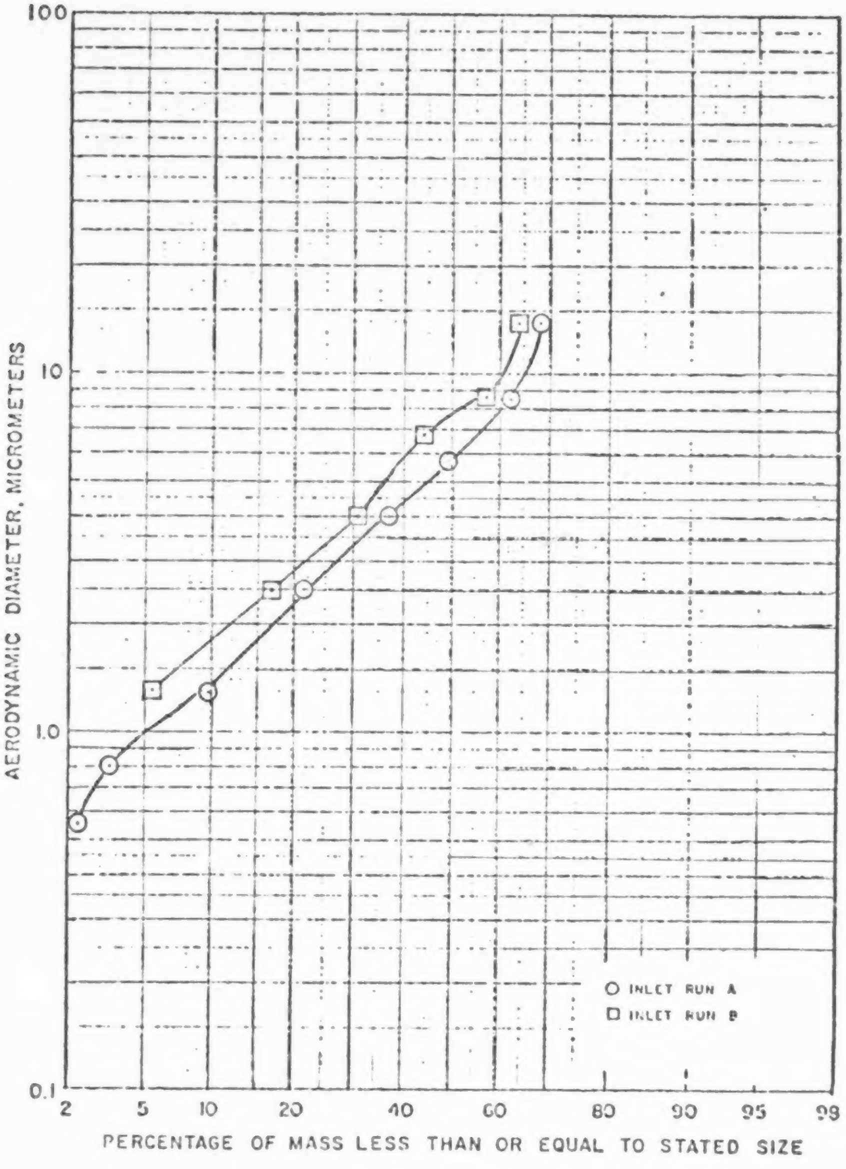


Figure 19. Inlet cumulative particle size distribution for run 3

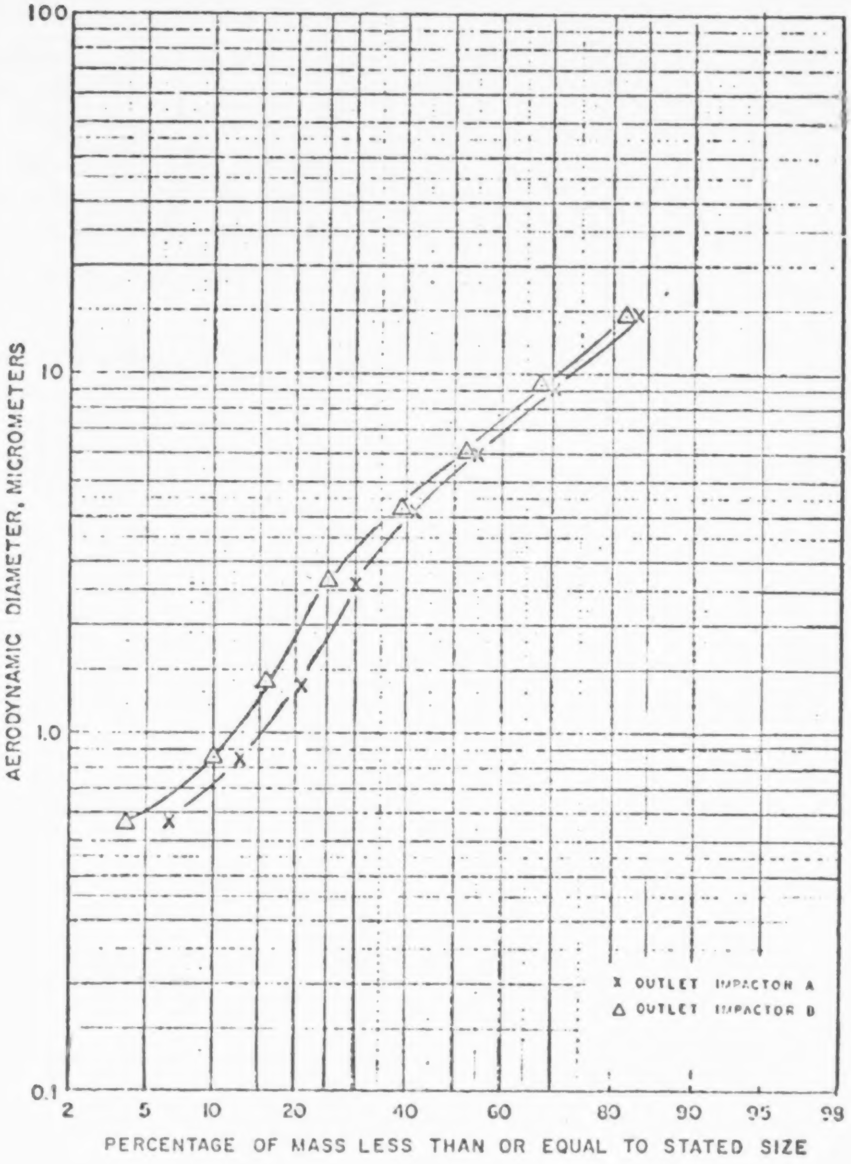


Figure 20. Outlet cumulative particle size distribution for run 3

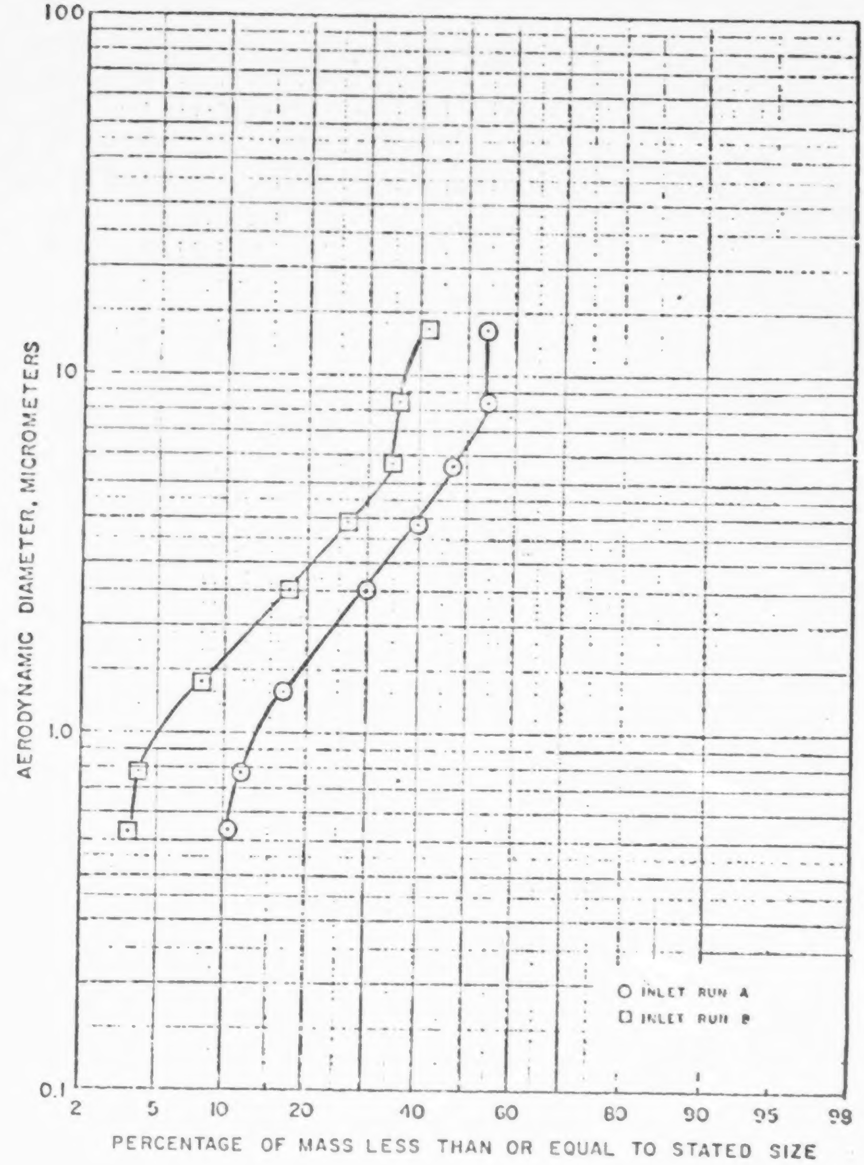


Figure 21. Inlet cumulative particle size distribution for run 4

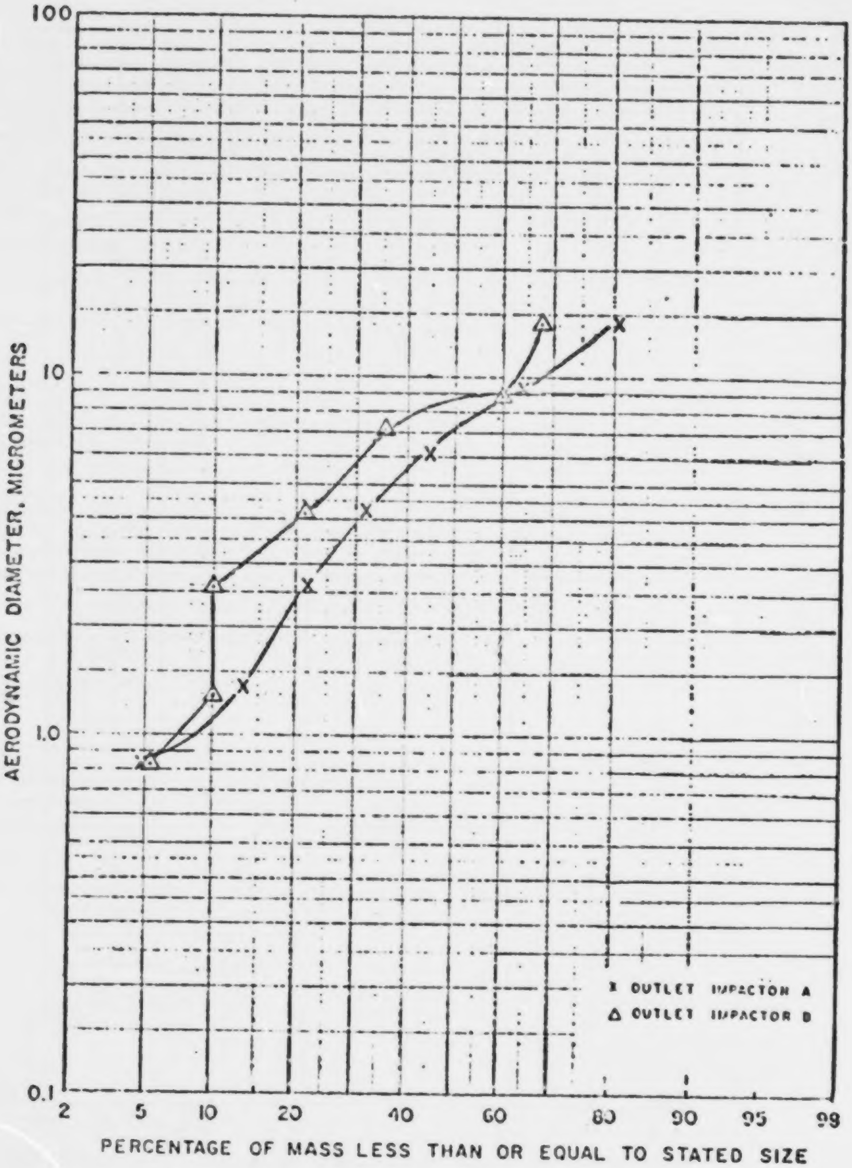


Figure 22. Outlet cumulative particle size distribution for run 4

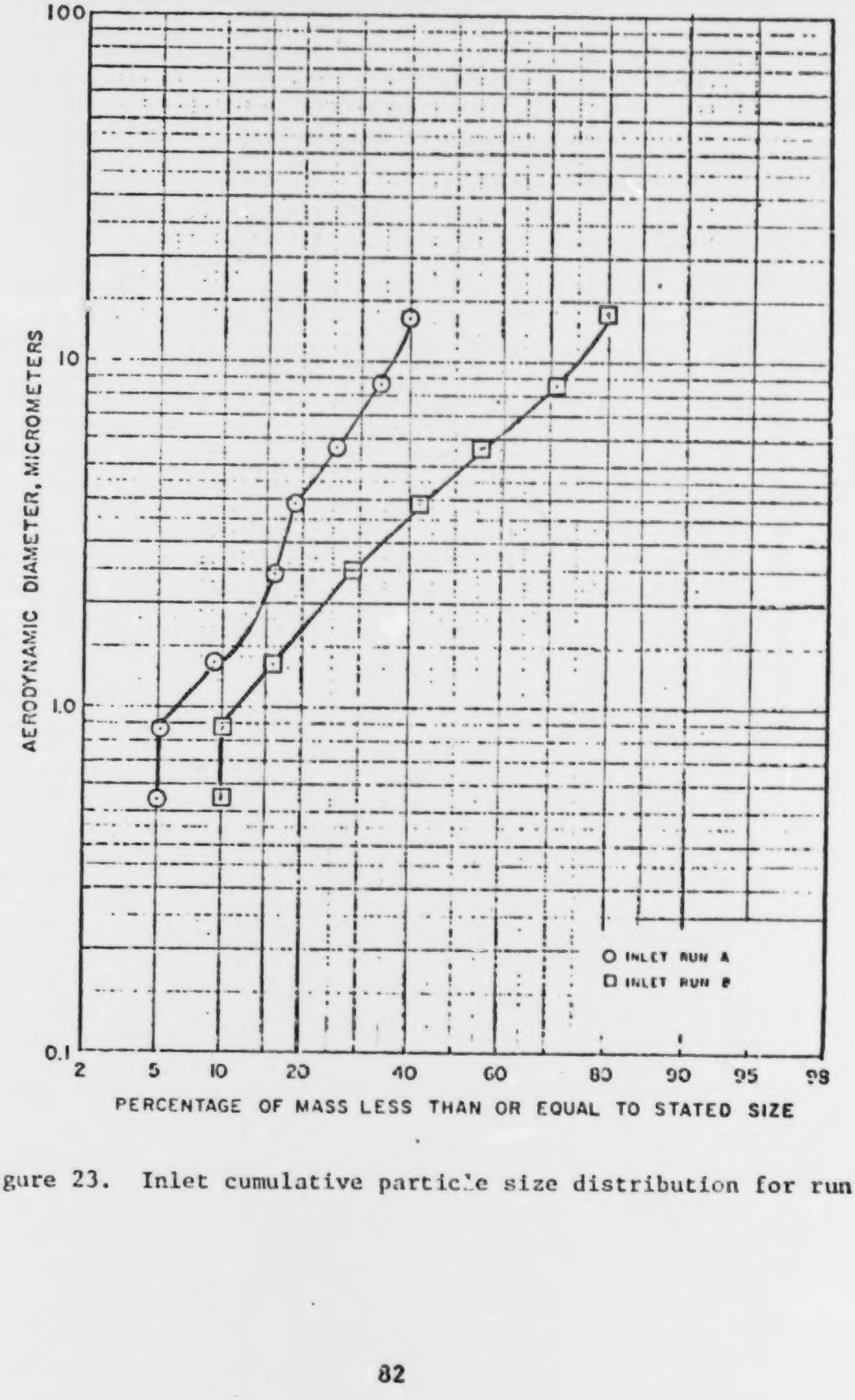


Figure 23. Inlet cumulative particle size distribution for run 5

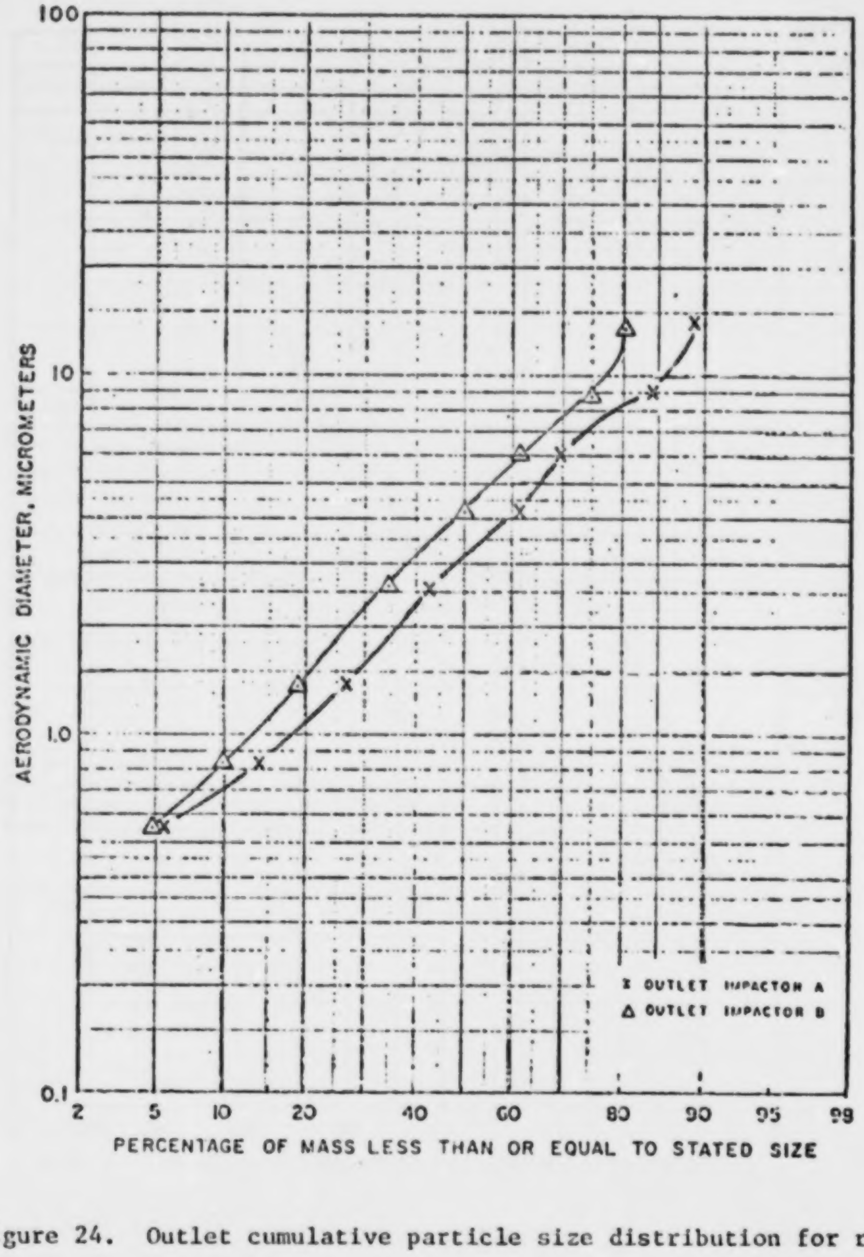


Figure 24. Outlet cumulative particle size distribution for run 5

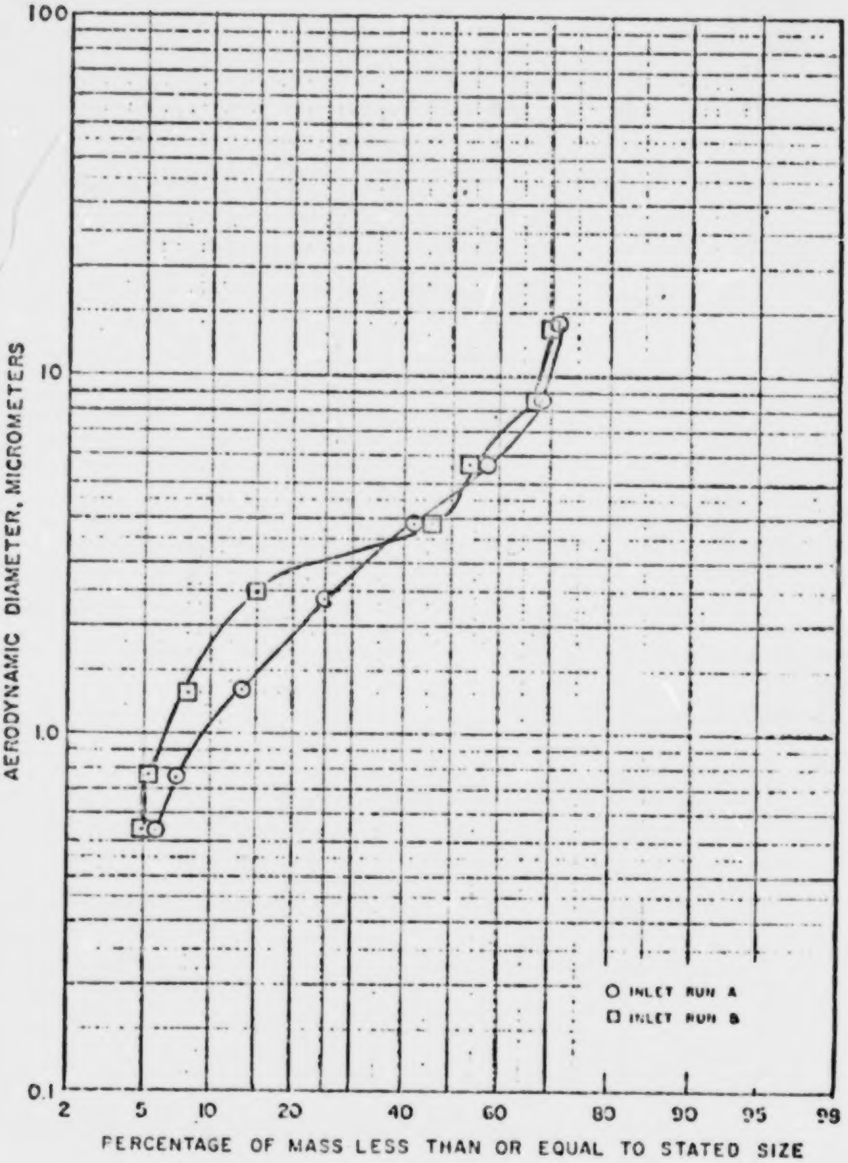


Figure 25. Inlet cumulative particle size distribution for run 6

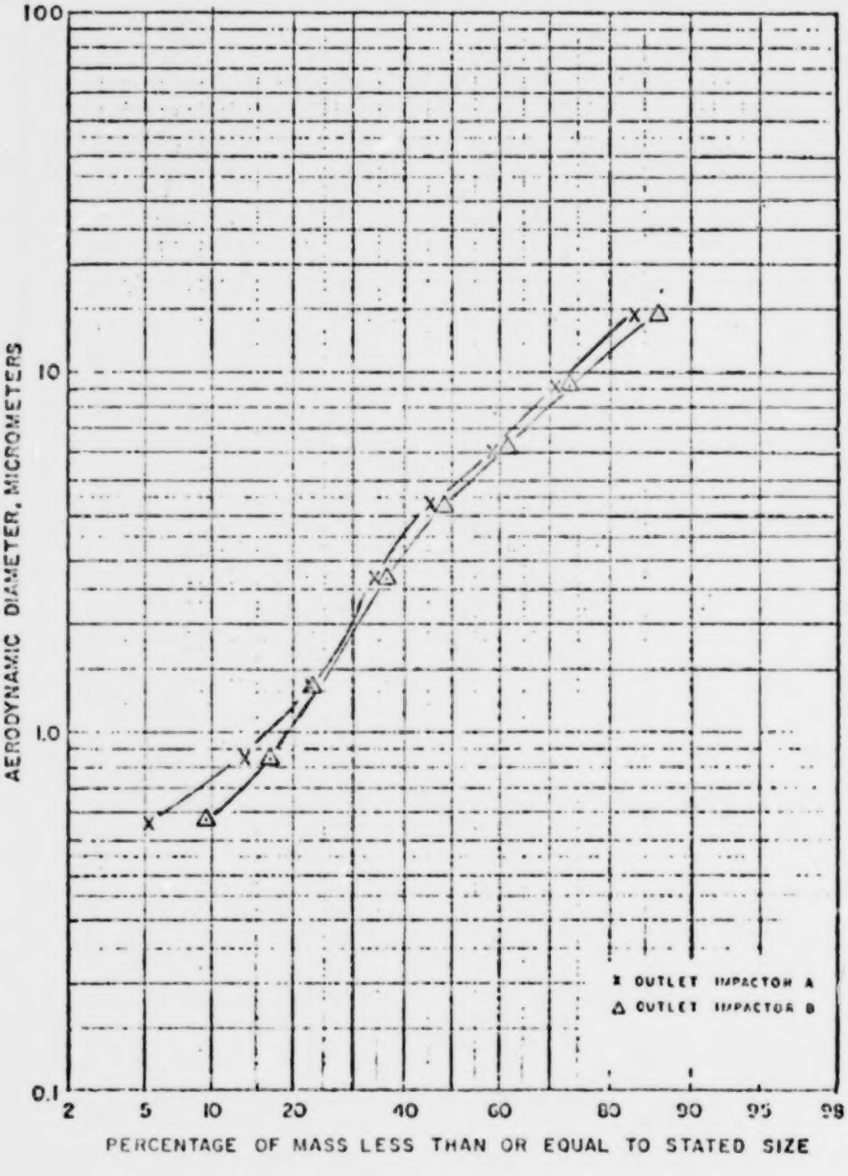


Figure 26. Outlet cumulative particle size distribution for run 6

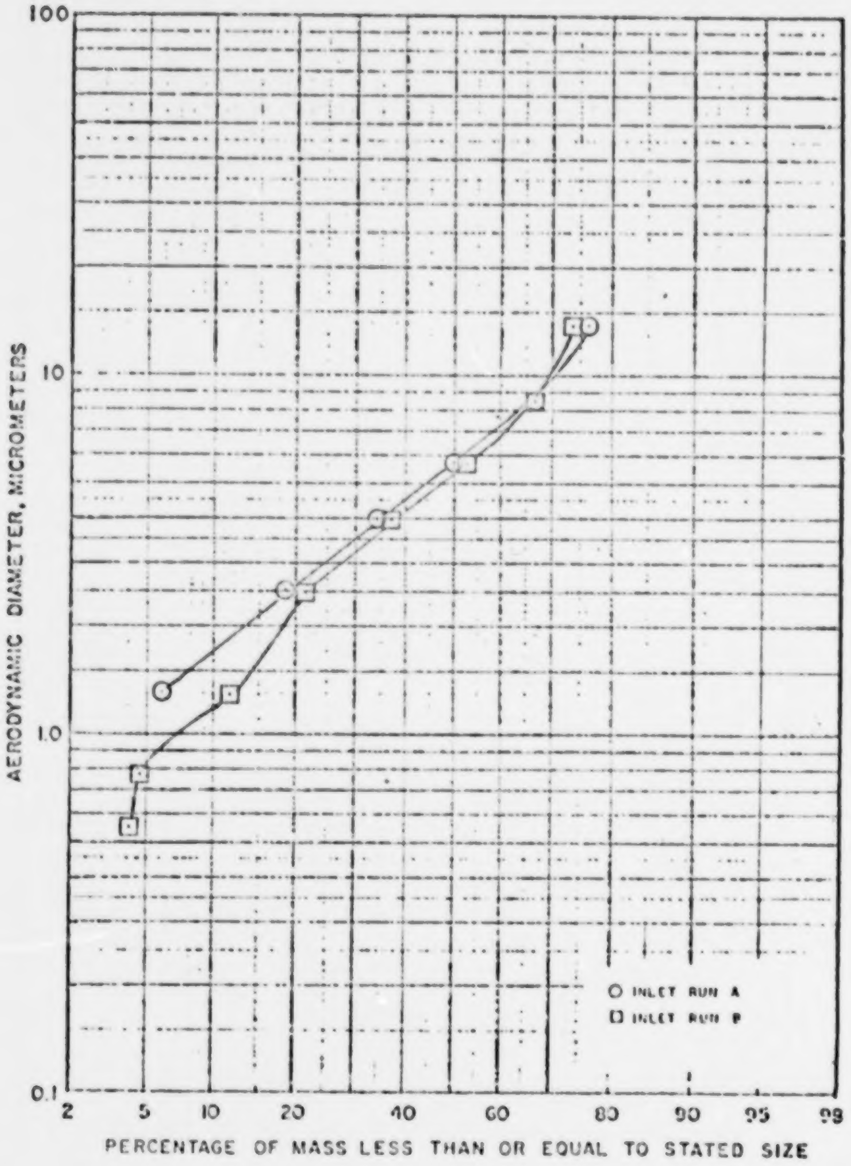


Figure 27. Inlet cumulative particle size distribution for run 7

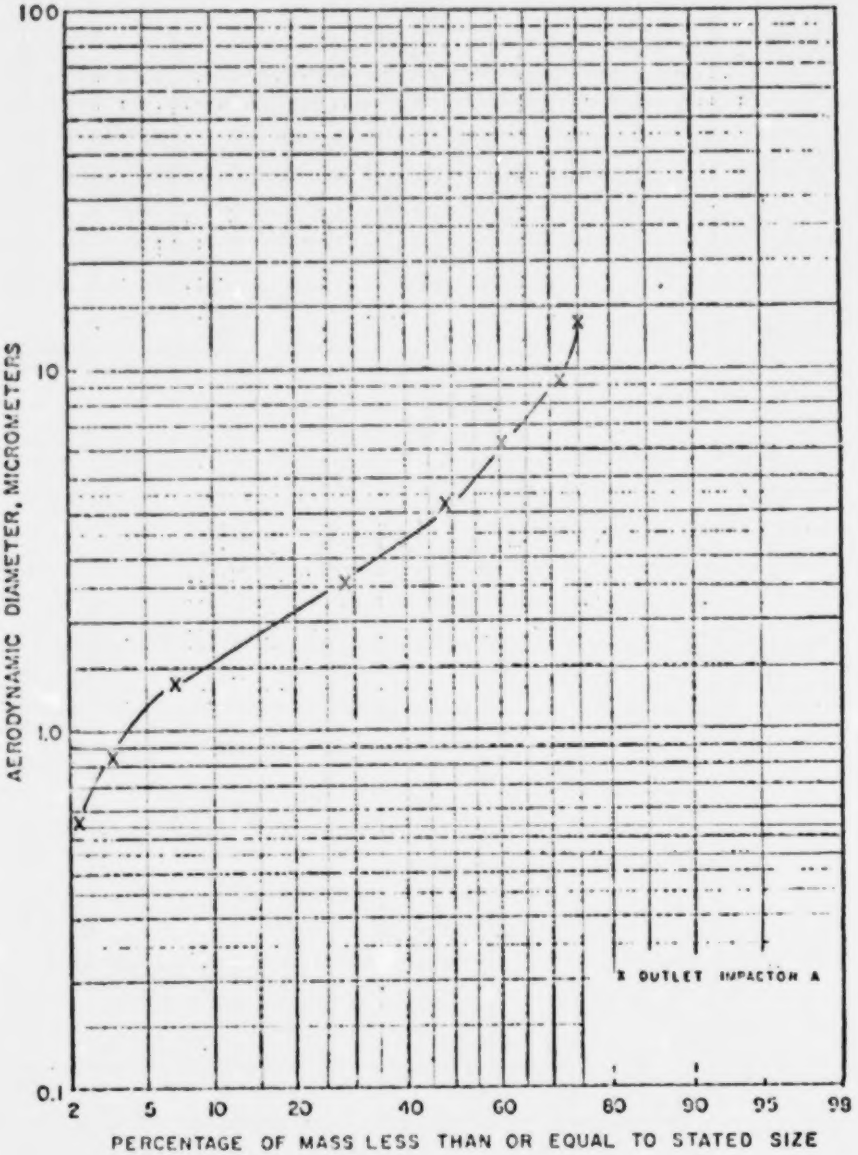


Figure 28. Outlet cumulative particle size distribution for run 7

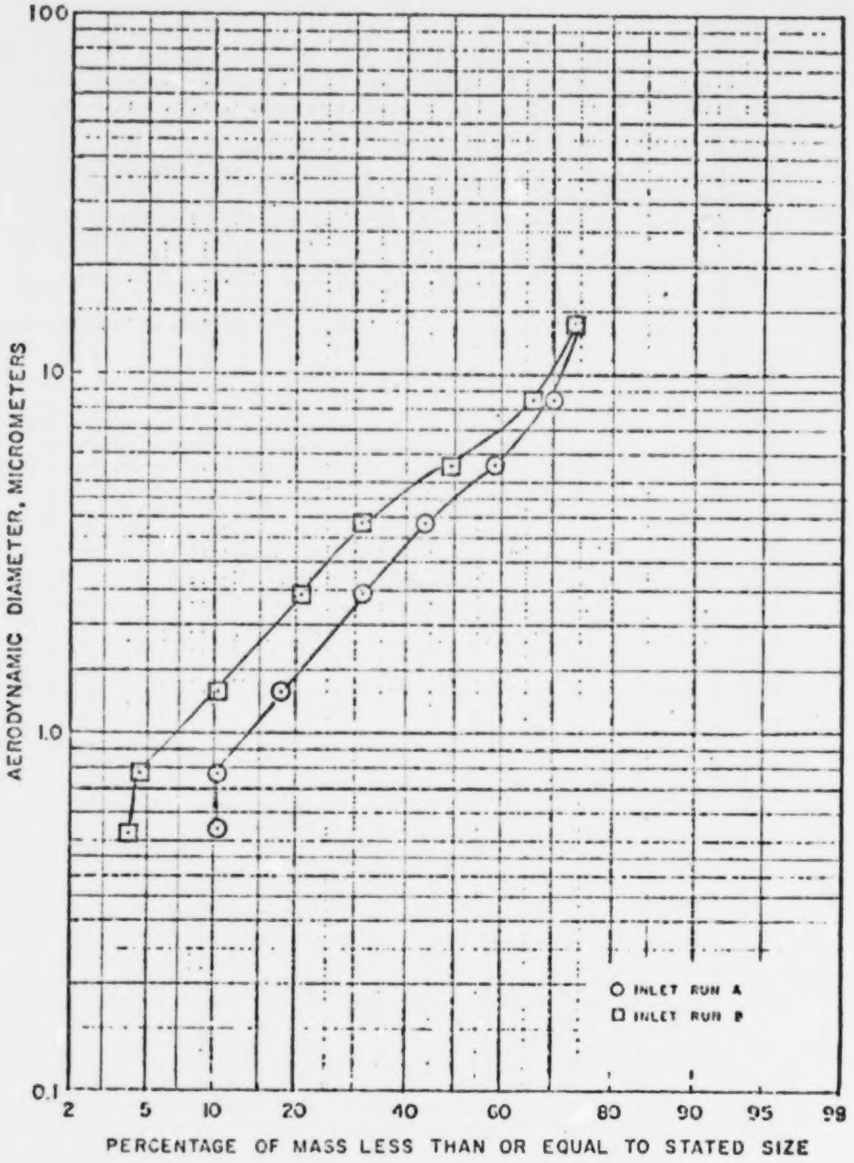


Figure 29. Inlet cumulative particle size distribution for run 8

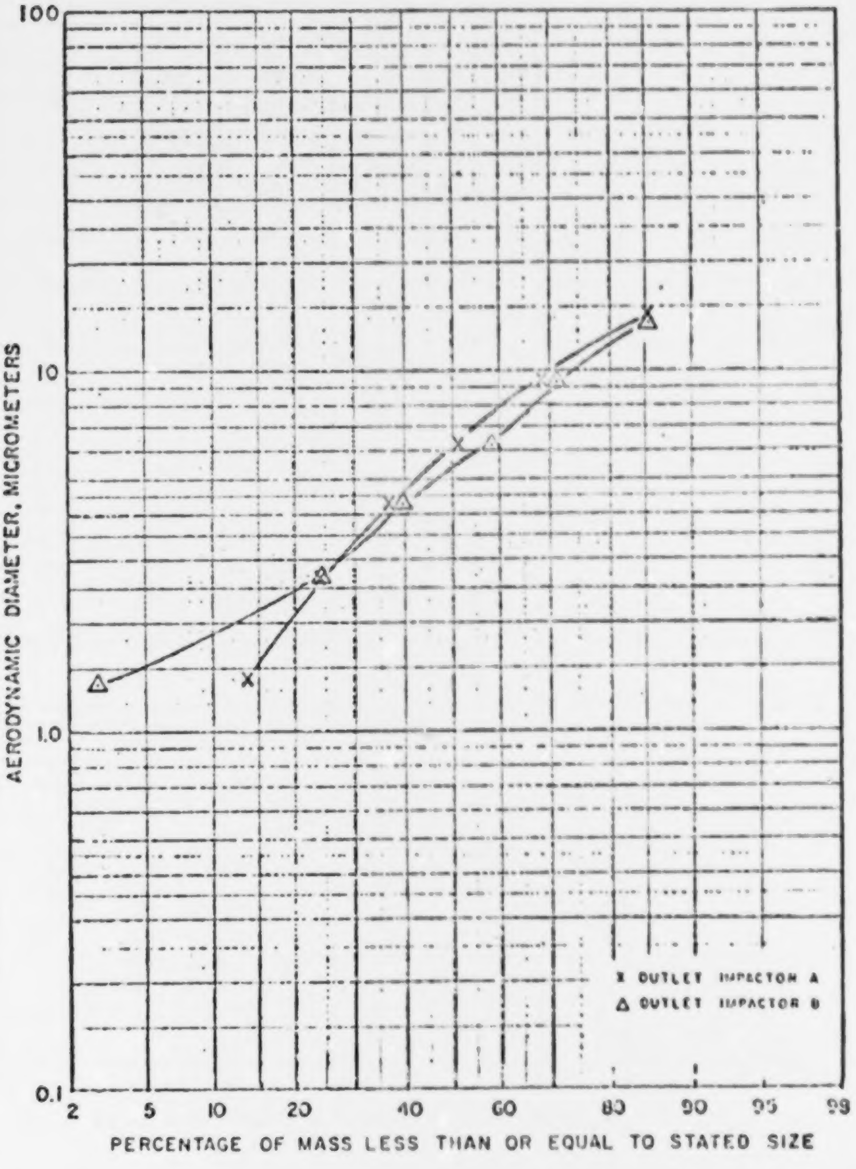


Figure 30. Outlet cumulative particle size distribution for run 8

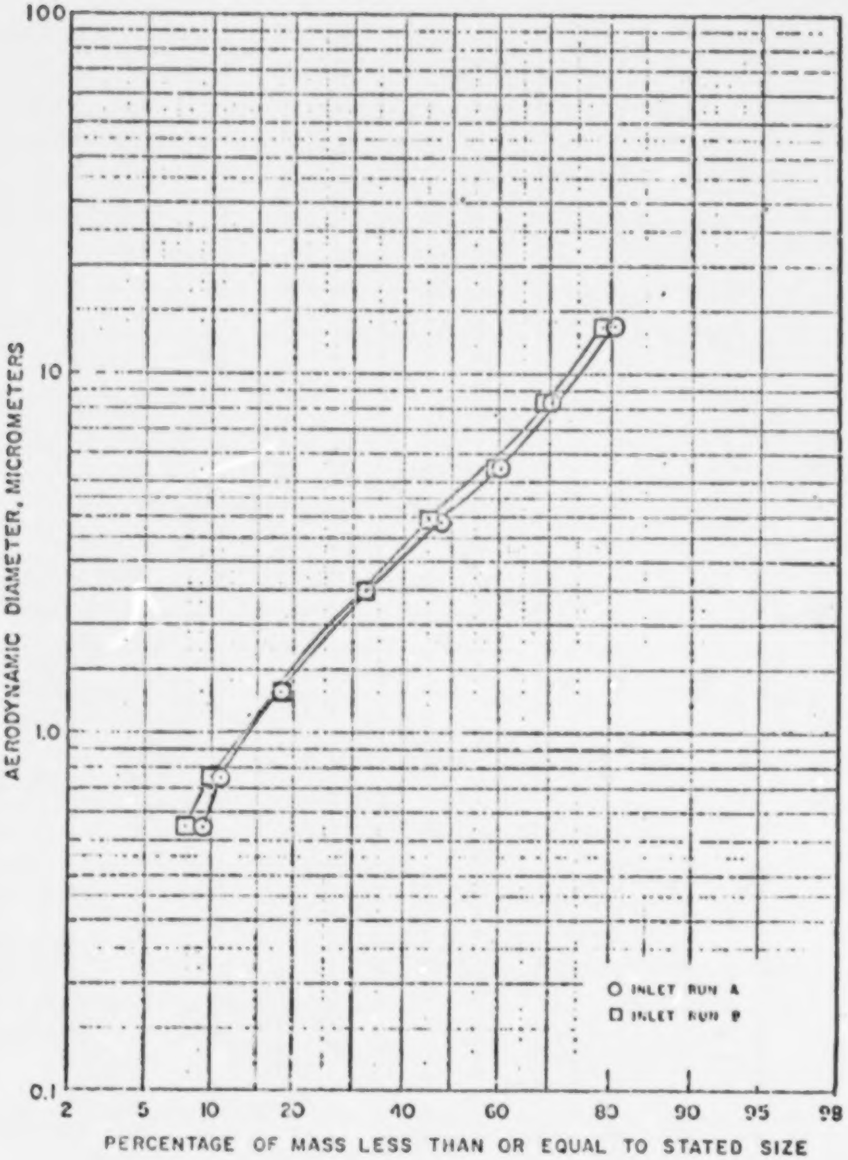


Figure 31. Inlet cumulative particle size distribution for run 9

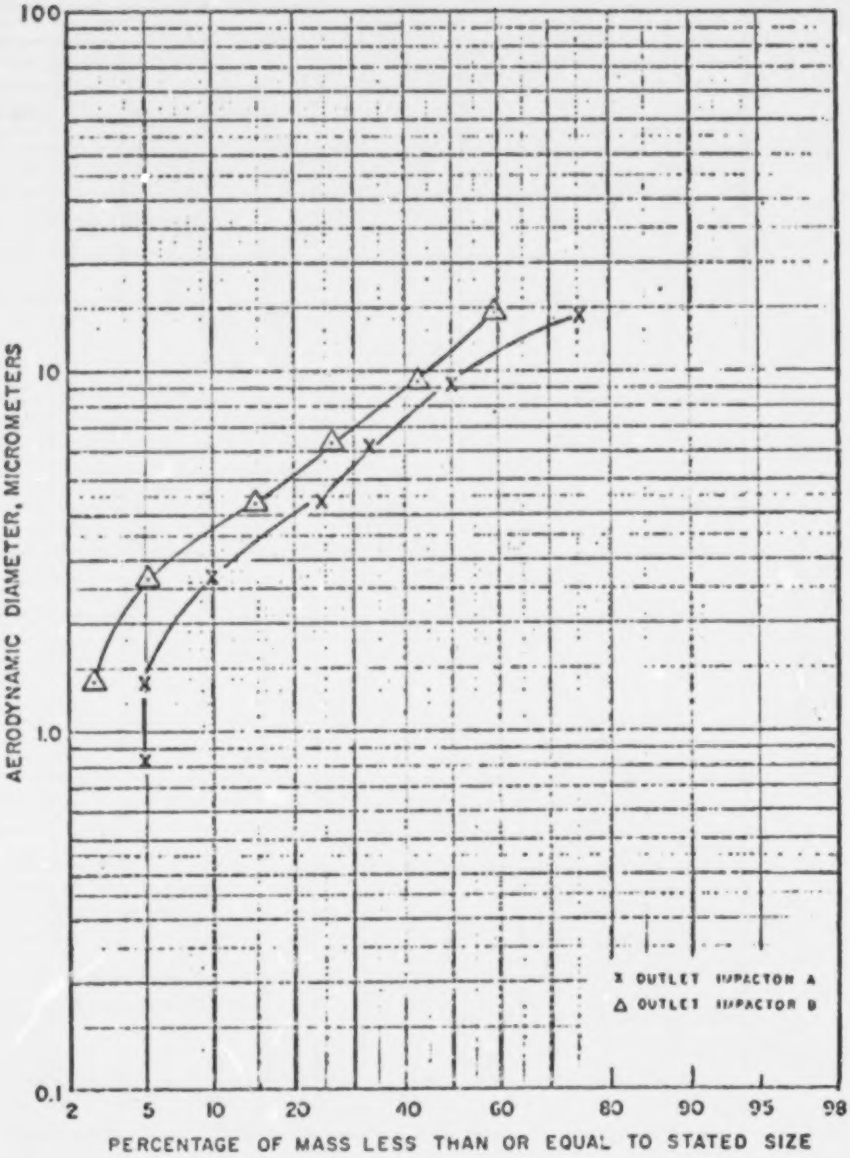


Figure 32. Outlet cumulative particle size distribution for run 9

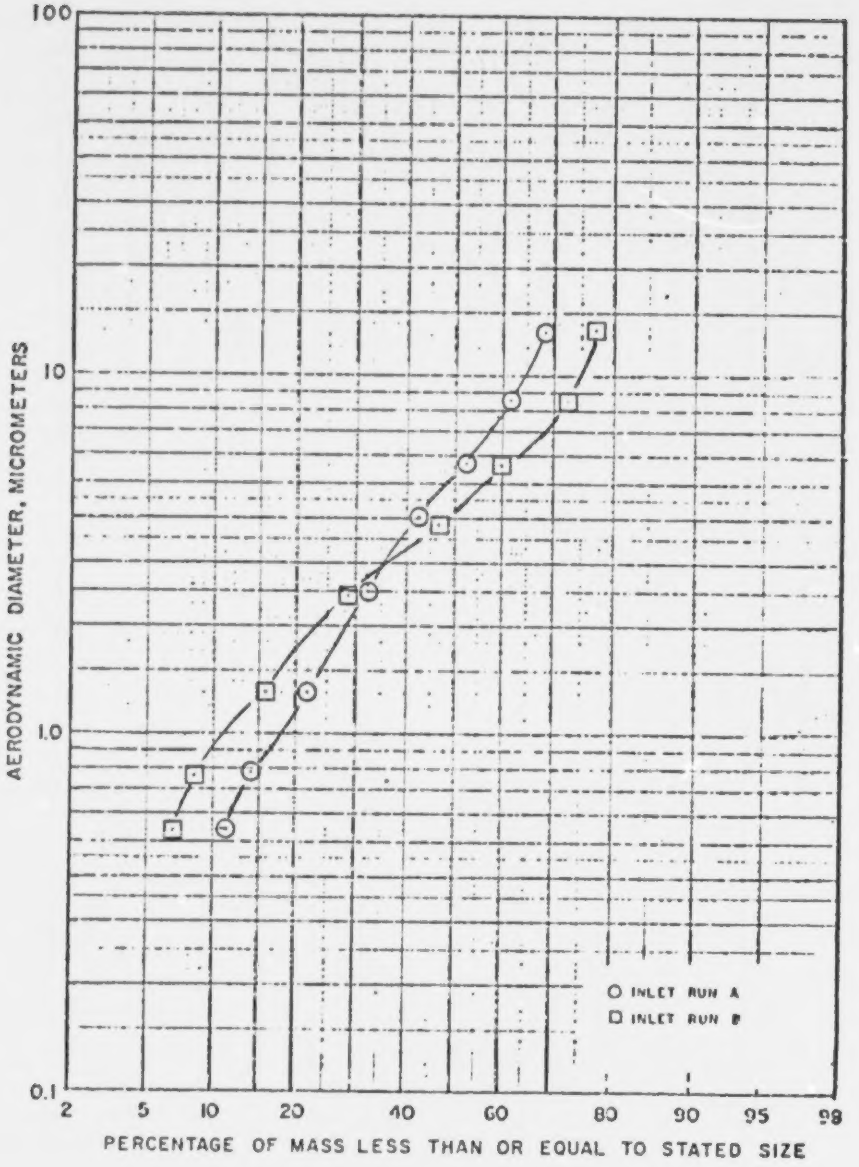


Figure 33. Inlet cumulative particle size distribution for run 10

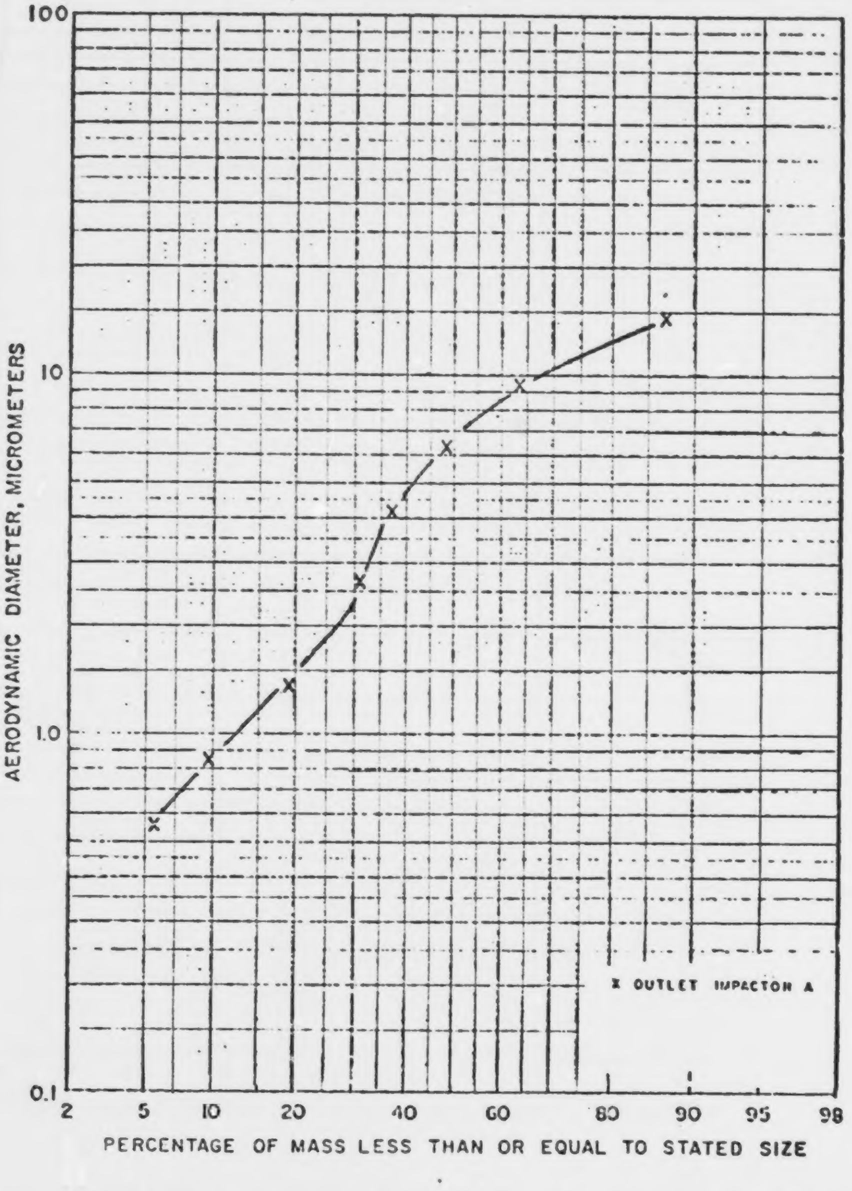


Figure 34. Outlet cumulative particle size distribution for run 10

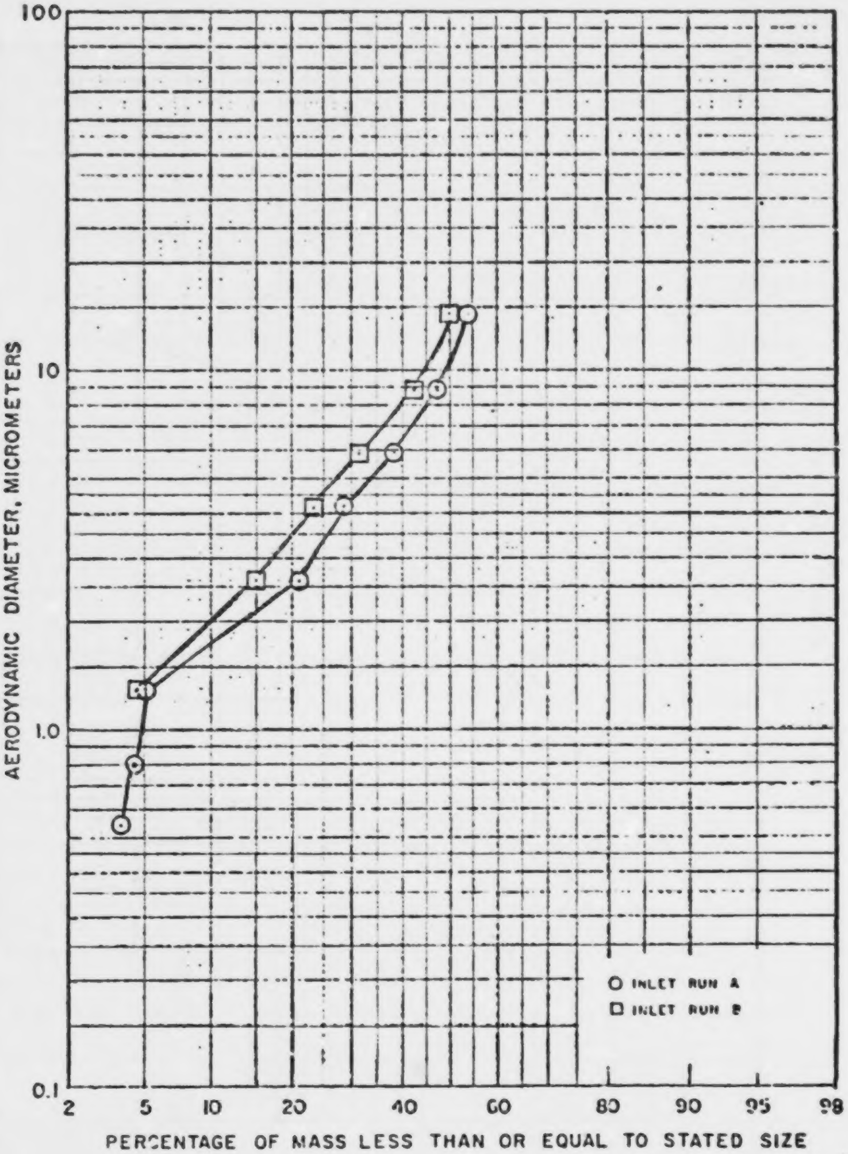


Figure 35. Inlet cumulative particle size distribution for run 11

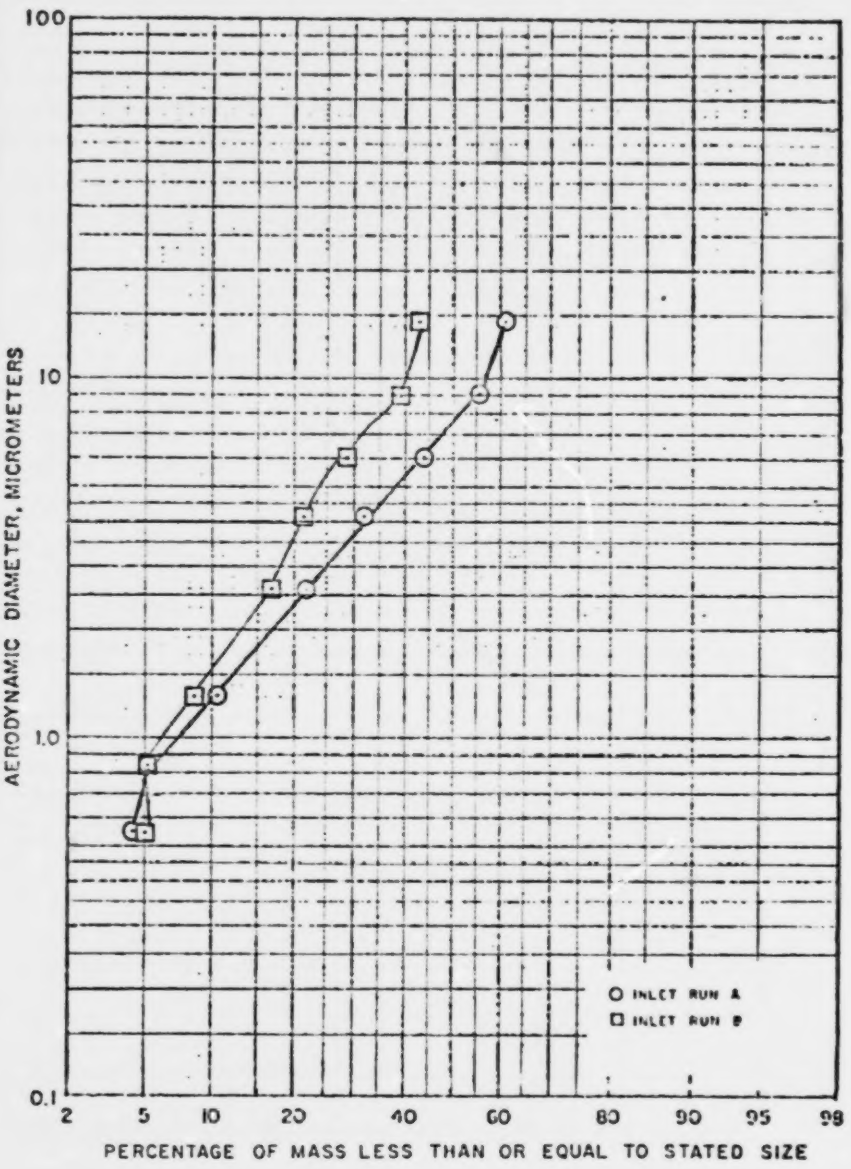


Figure 36. Inlet cumulative particle size distribution for run 12

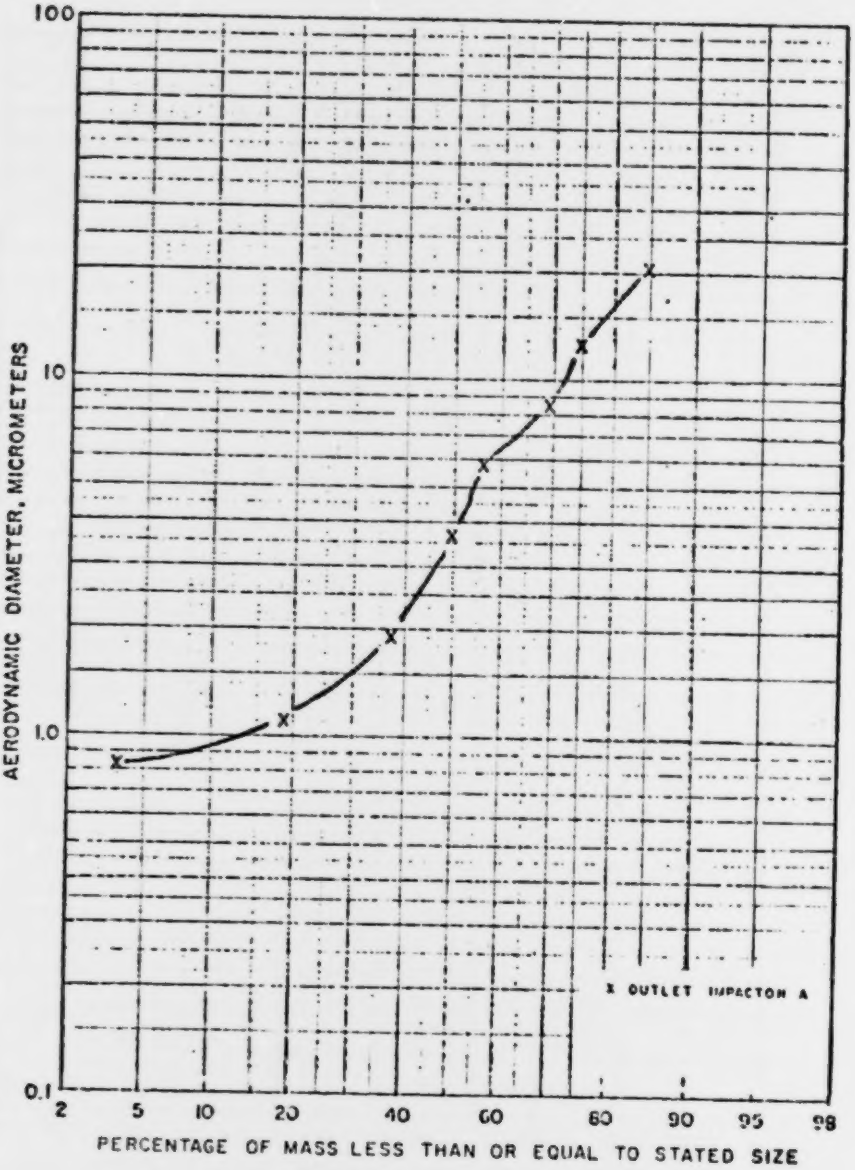


Figure 37. Outlet cumulative particle size distribution for run 12

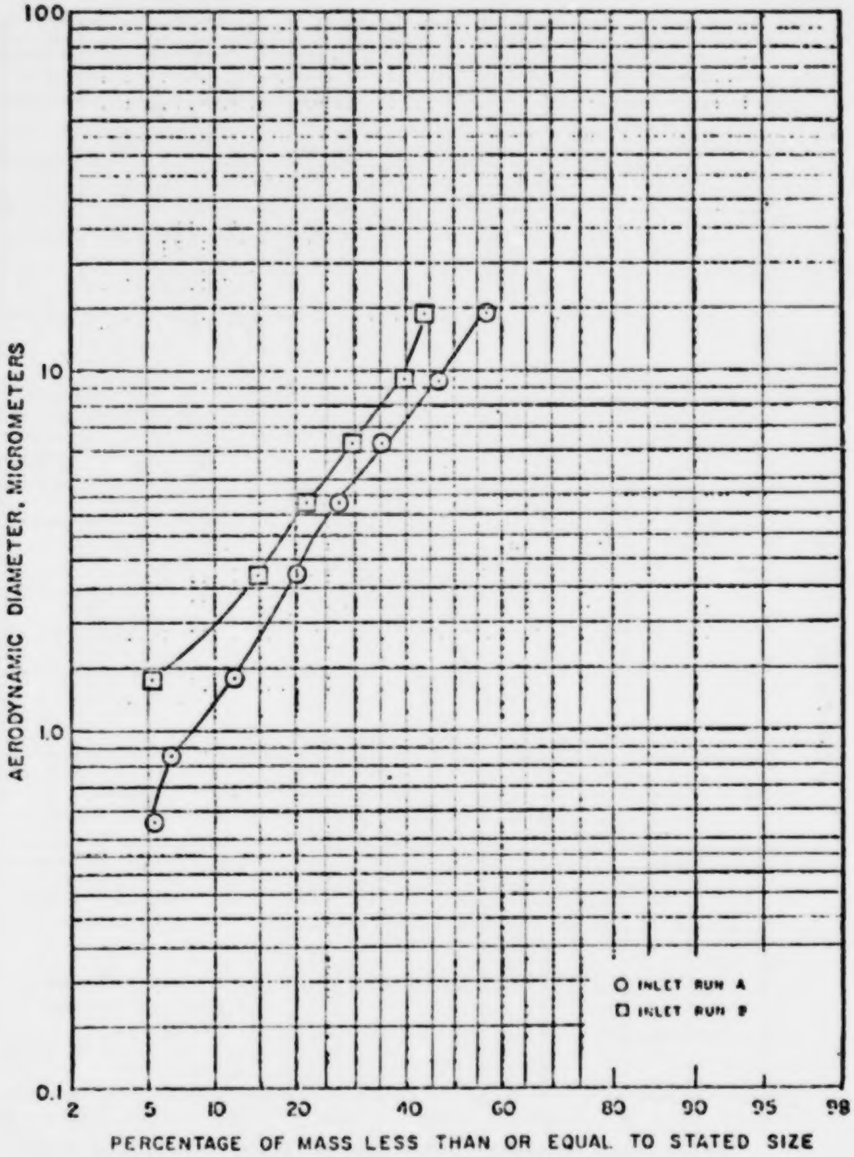


Figure 38. Inlet cumulative particle size distribution for run 13

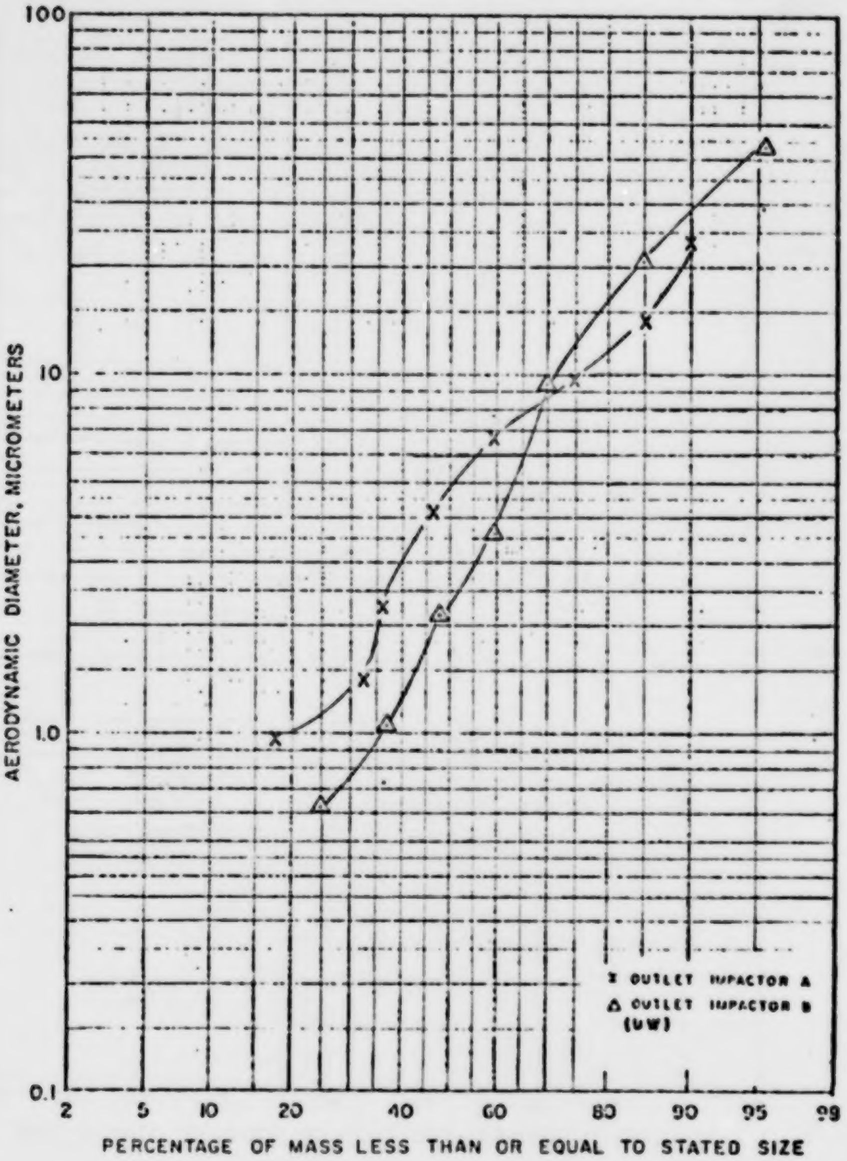


Figure 39. Outlet cumulative particle size distribution for run 13

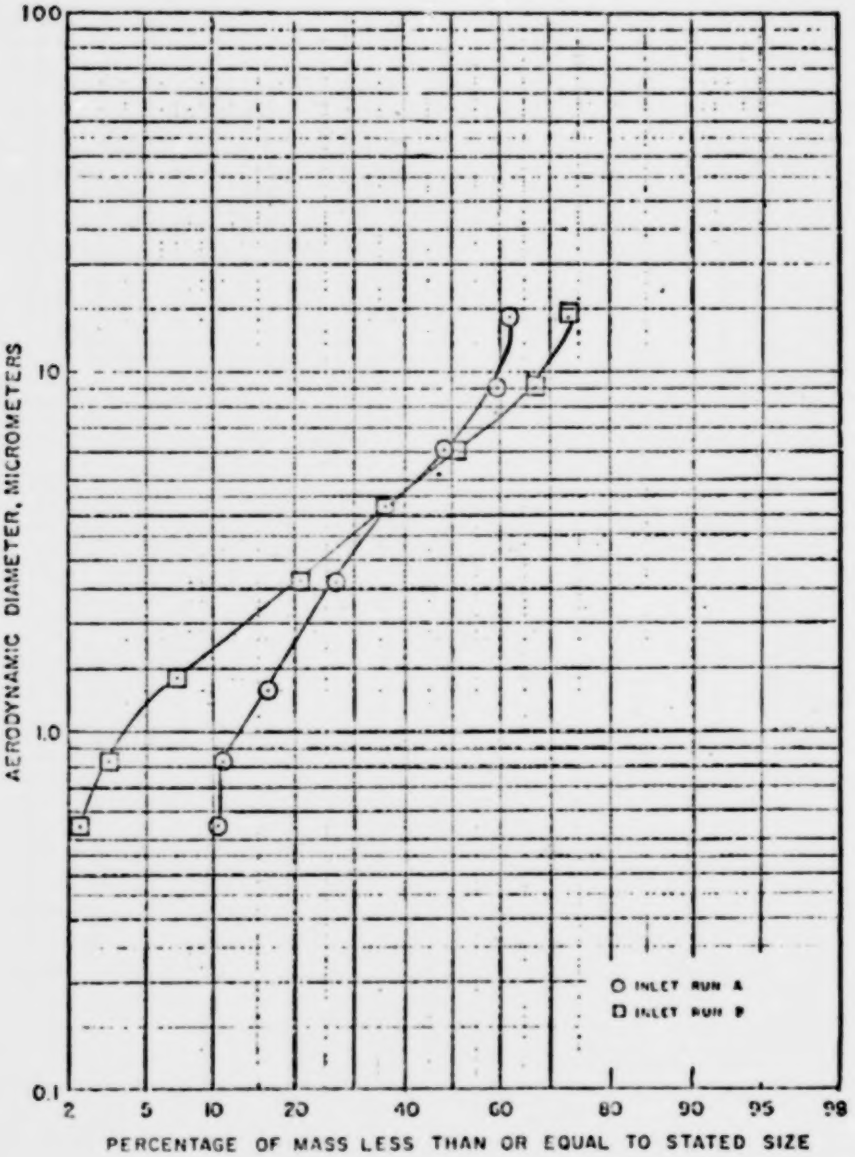


Figure 40. Inlet cumulative particle size distribution for run 14

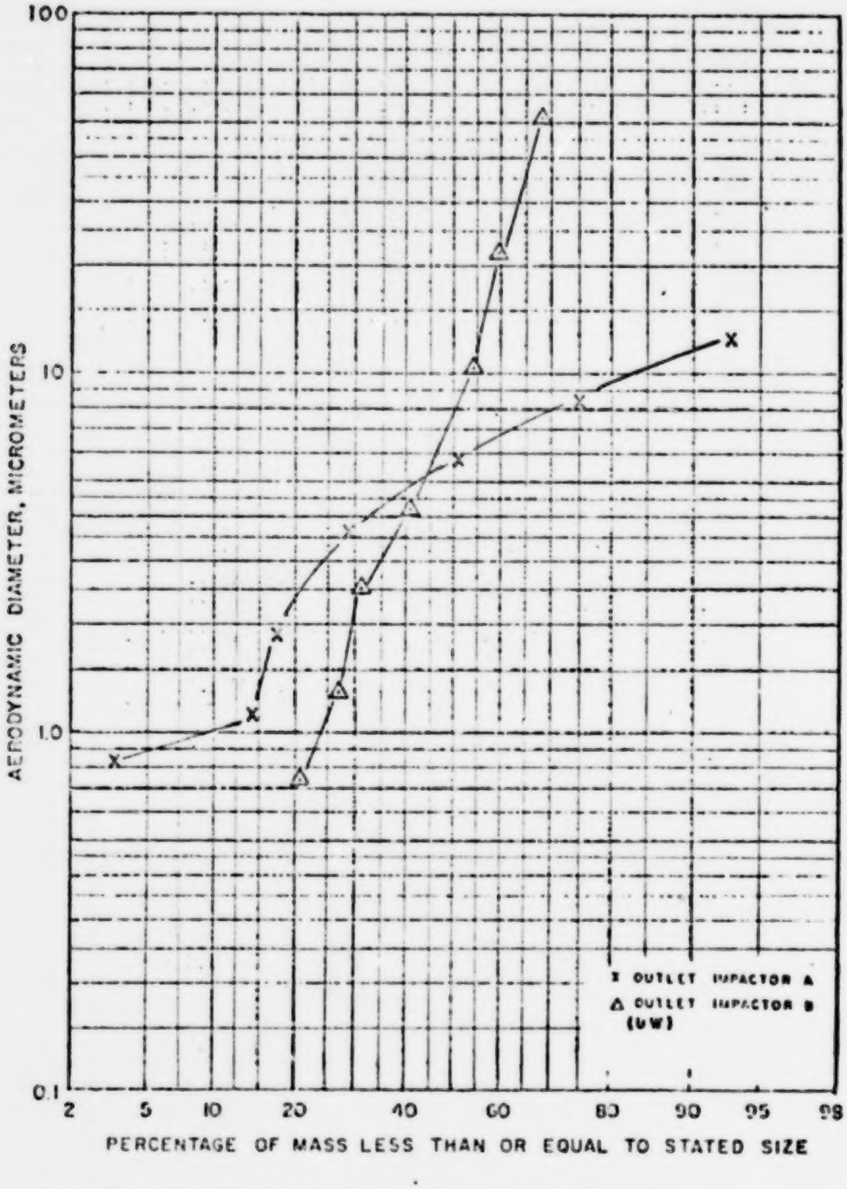


Figure 41. Outlet cumulative particle size distribution for run 14

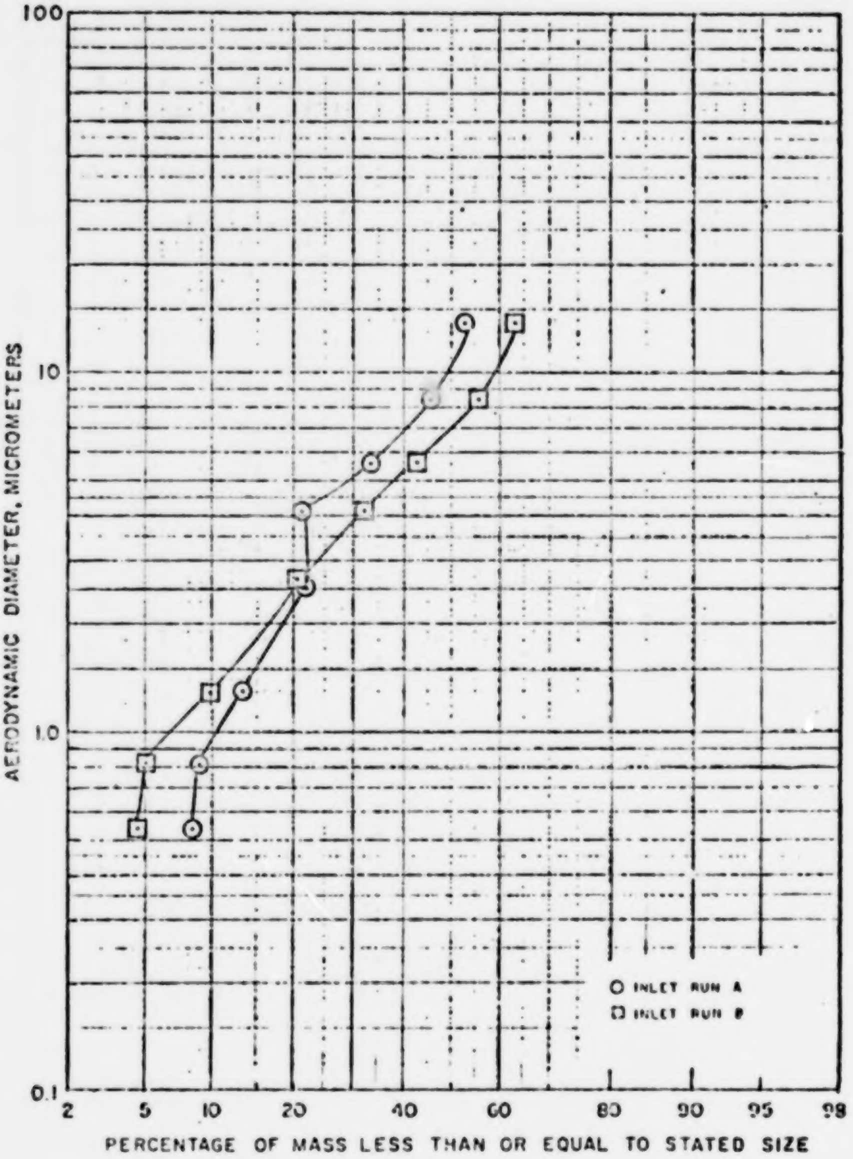


Figure 42. Inlet cumulative particle size distribution for run 15

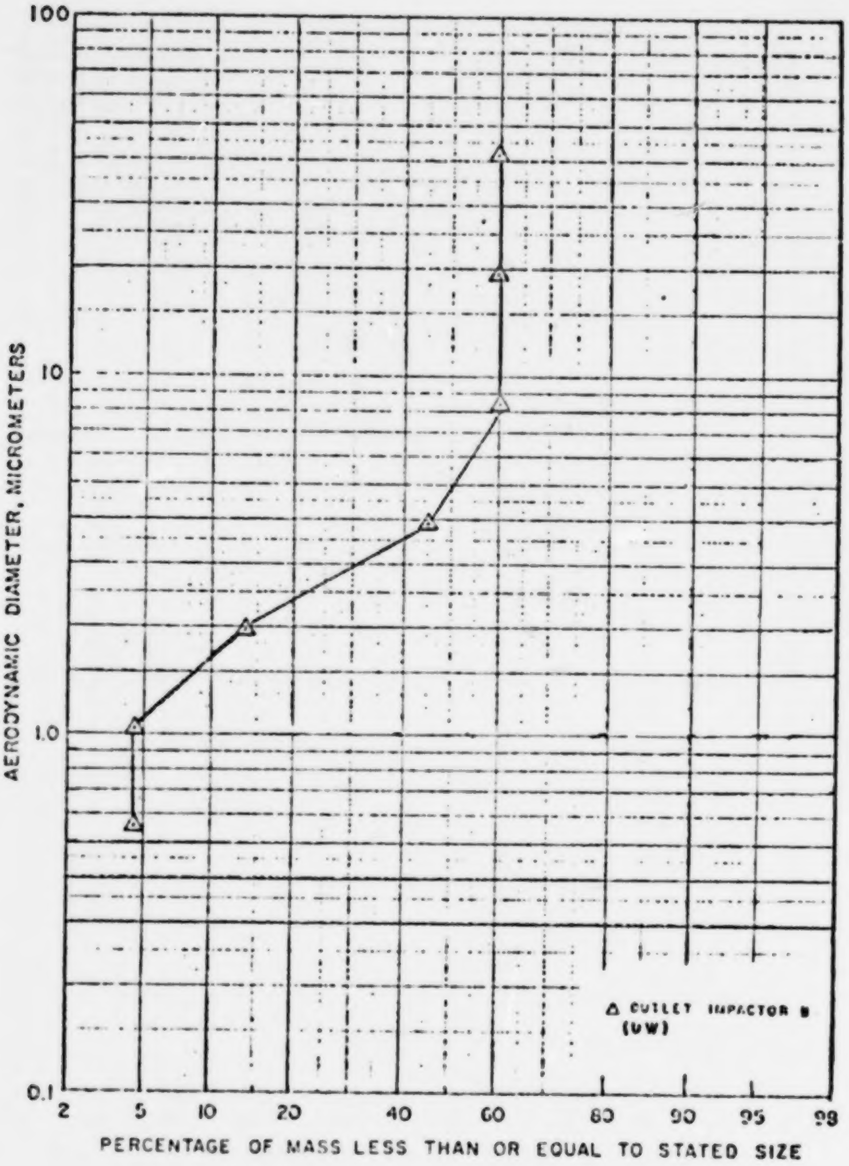


Figure 43. Outlet cumulative particle size distribution for run 15

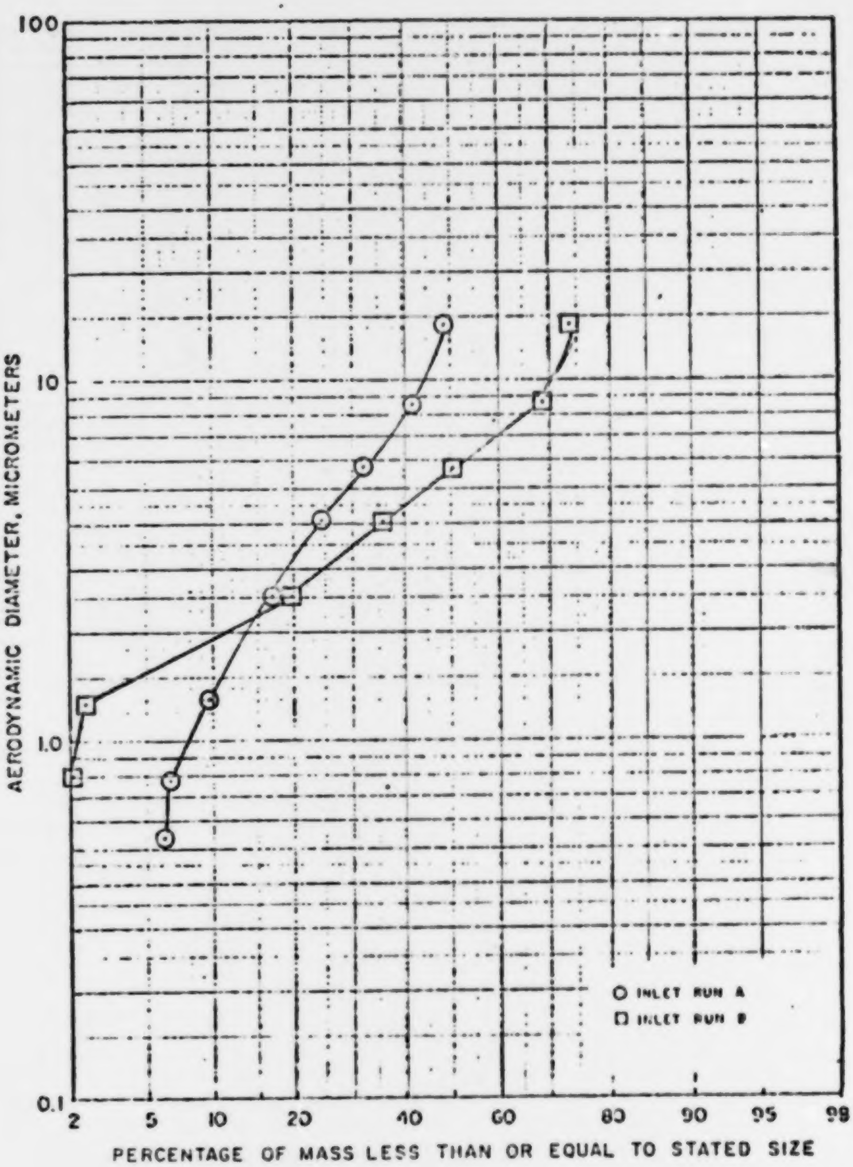


Figure 44. Inlet cumulative particle size distribution for run 16

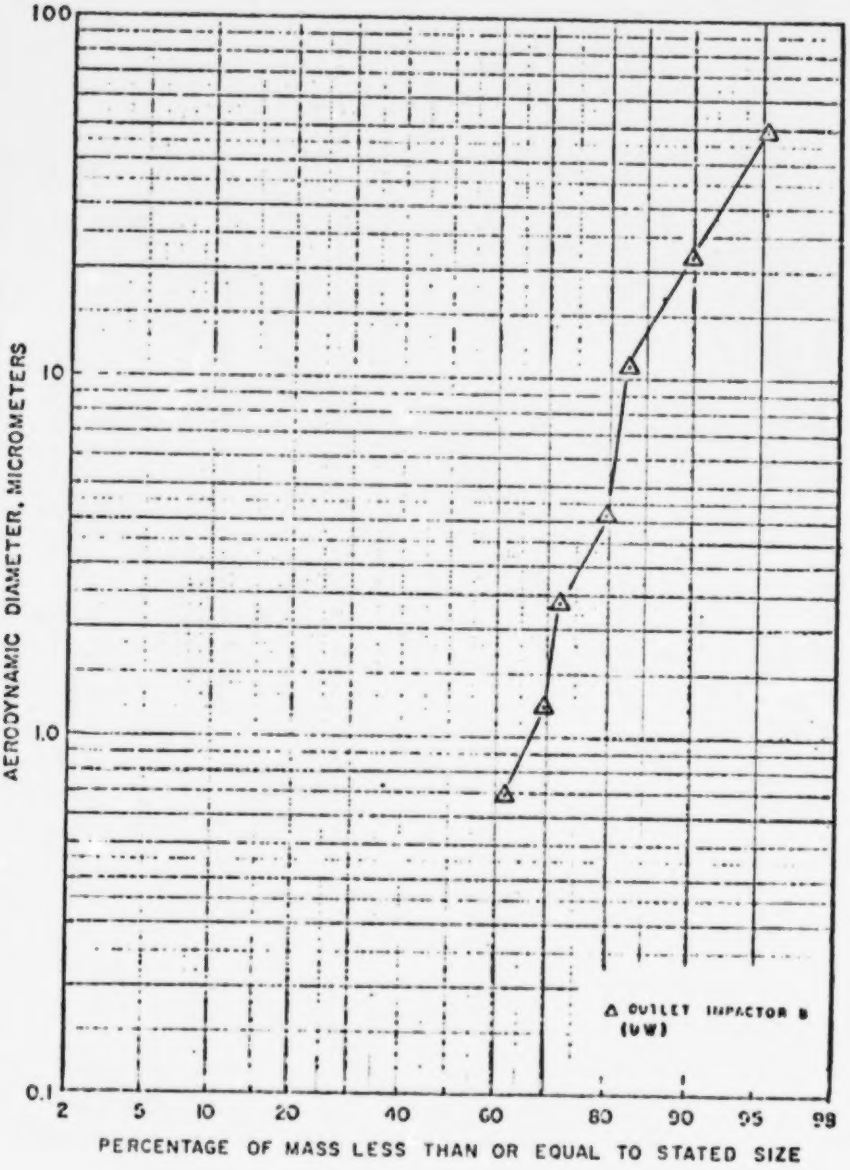


Figure 45. Outlet cumulative particle size distribution for run 16

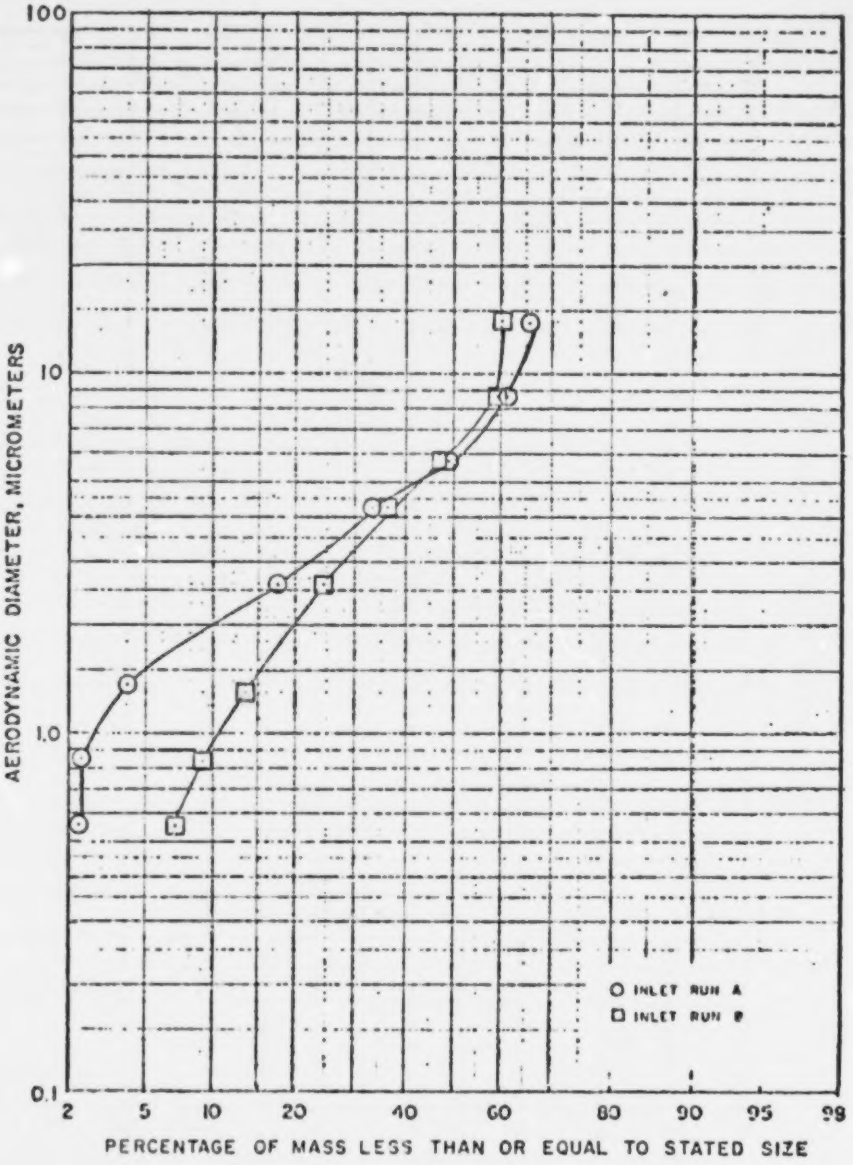


Figure 46. Inlet cumulative particle size distribution for run 17

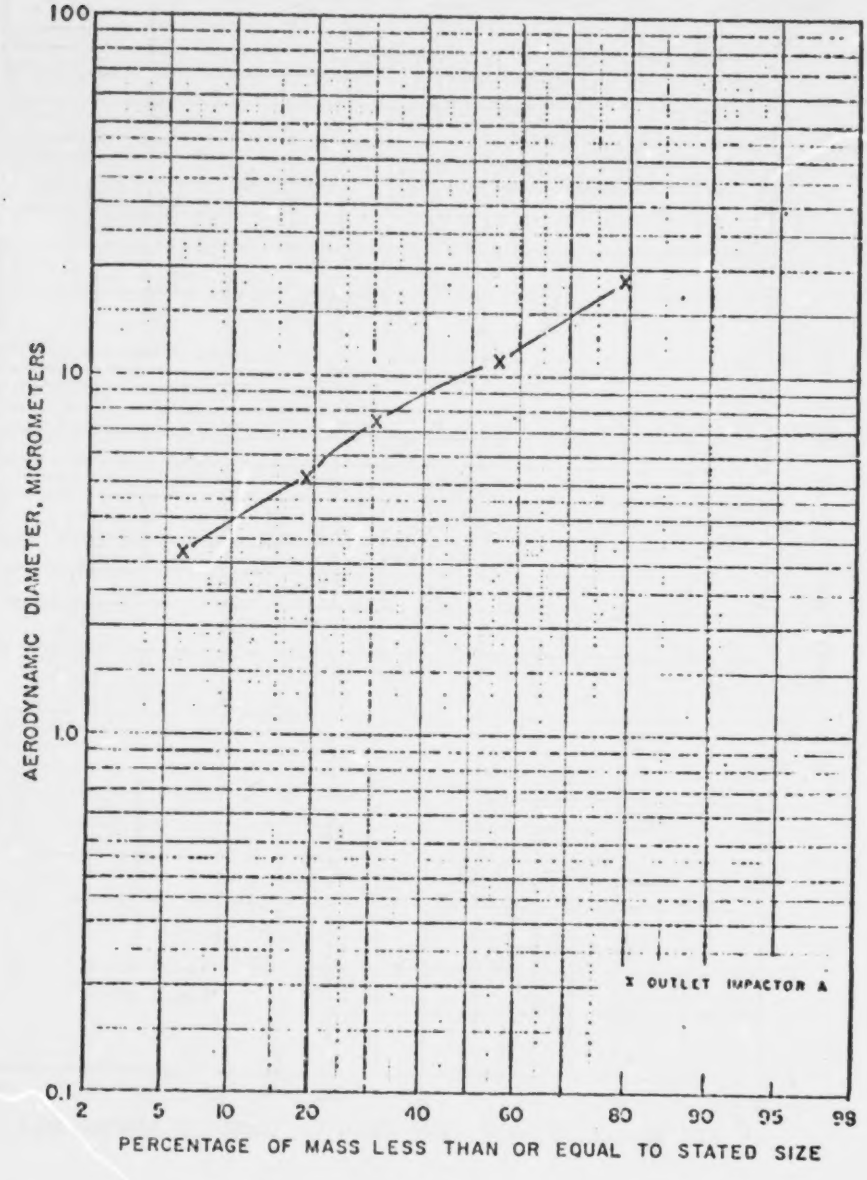


Figure 47. Outlet cumulative particle size distribution for run 17

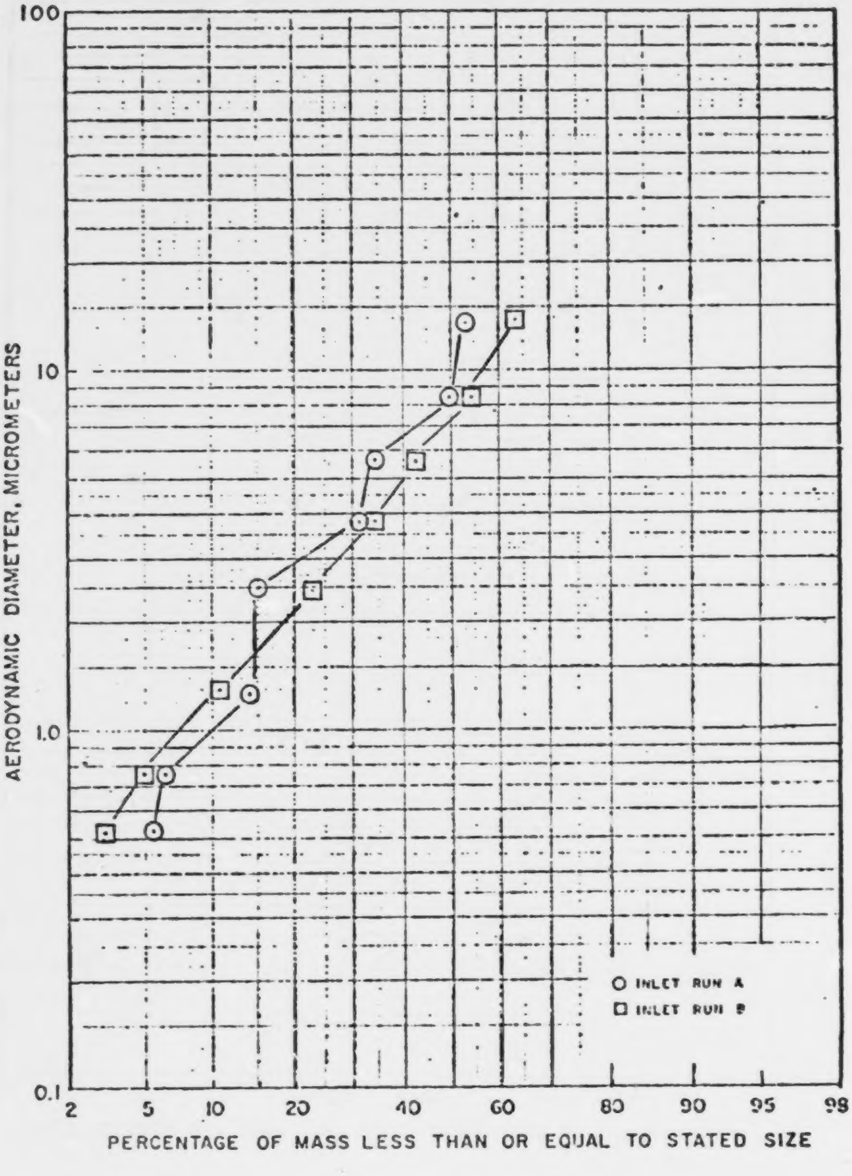


Figure 48. Inlet cumulative particle size distribution for run 18

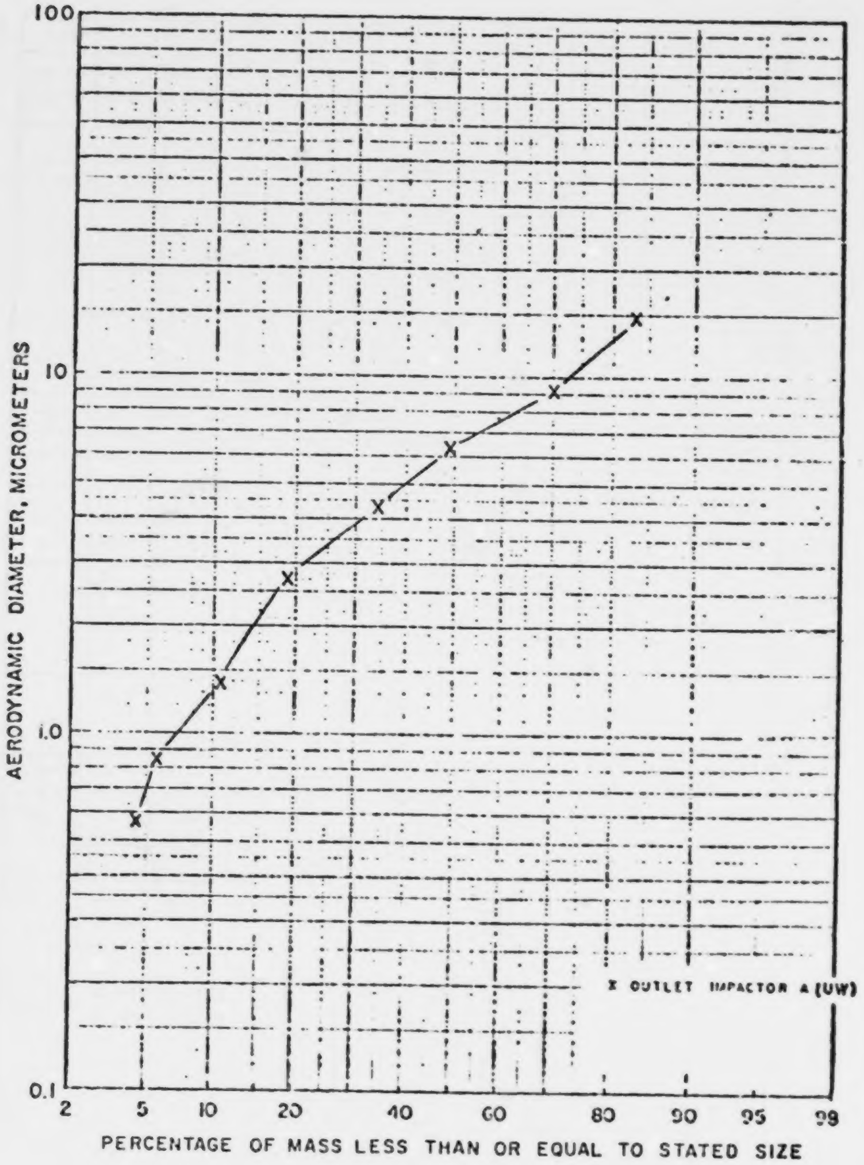


Figure 49. Outlet cumulative particle size distribution for run 18

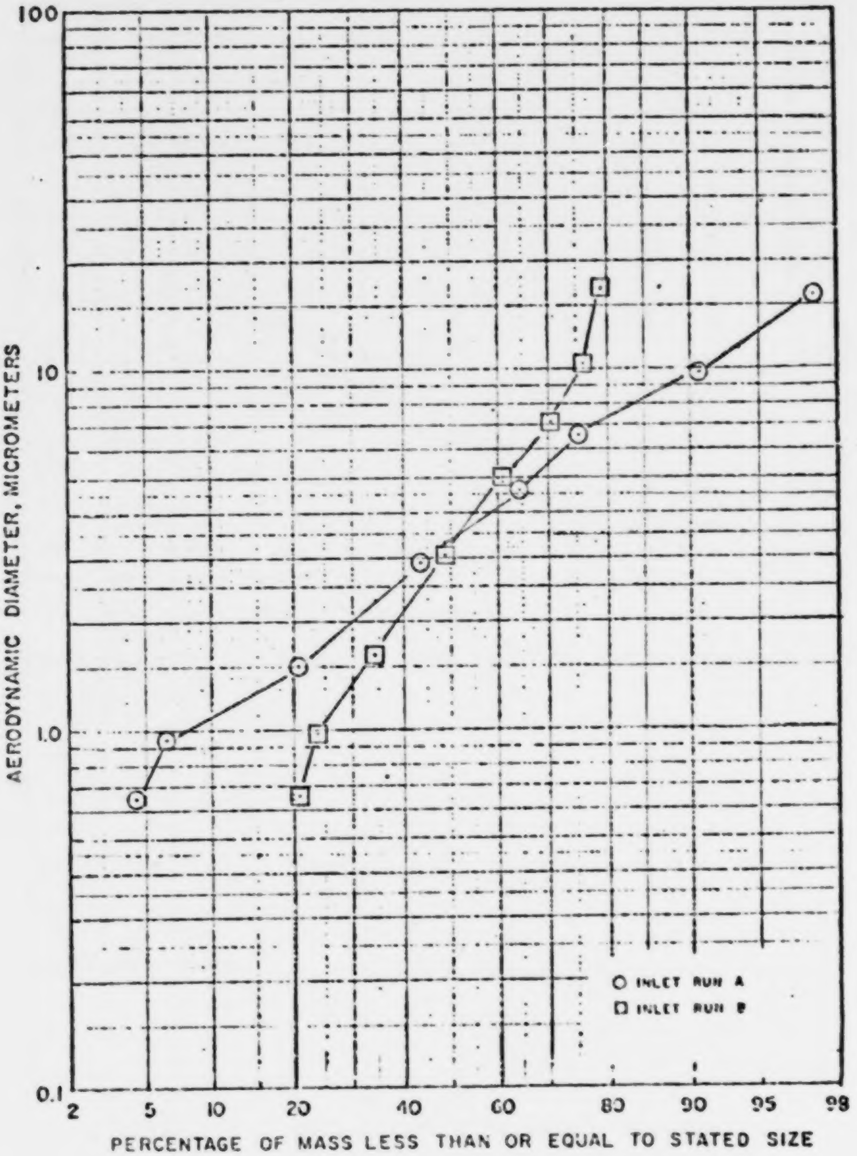


Figure 50. Inlet cumulative particle size distribution for run 19

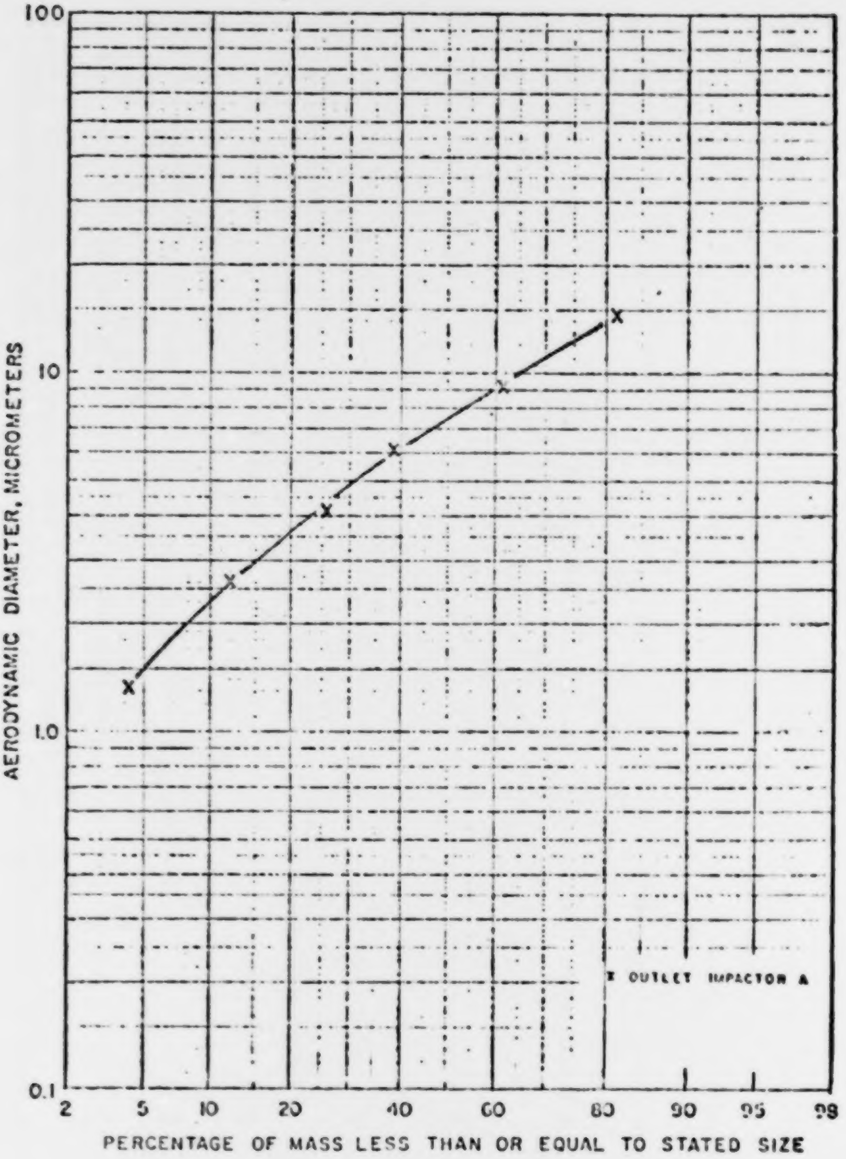


Figure 51. Outlet cumulative particle size distribution for run 19

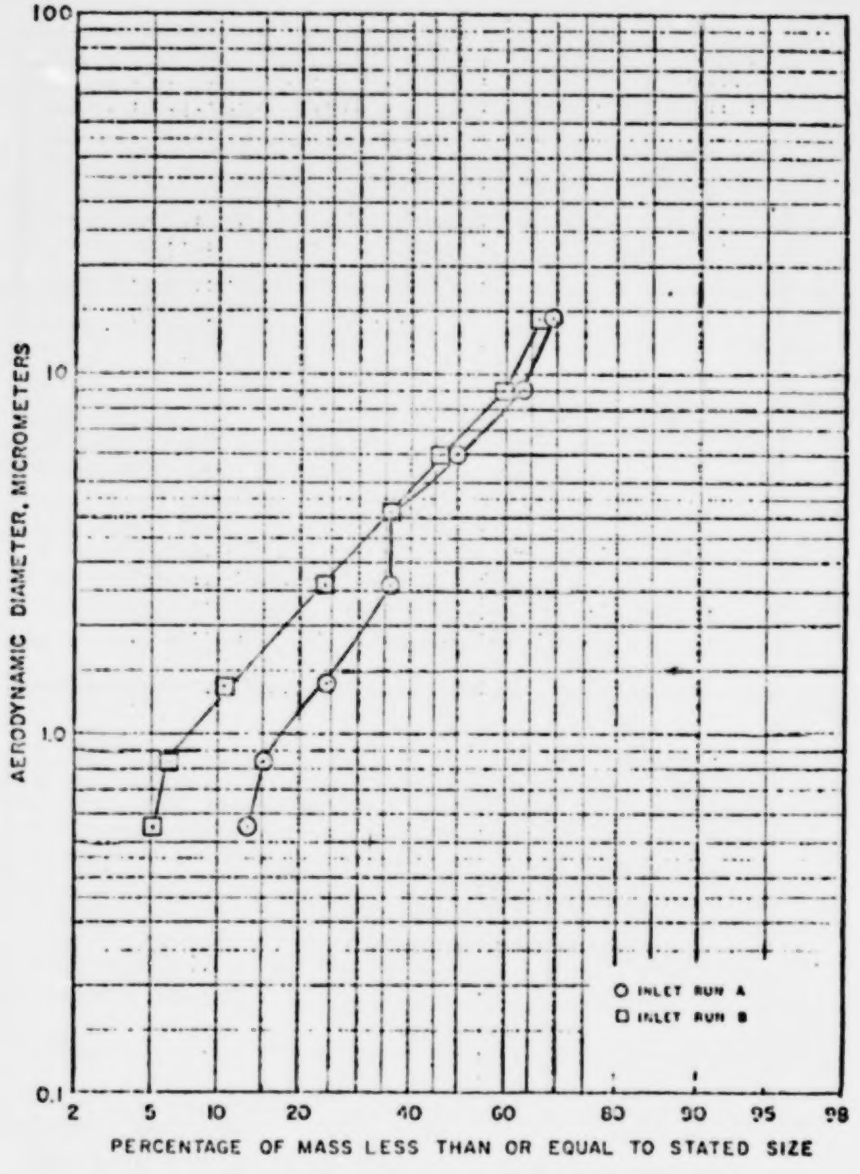


Figure 52. Inlet cumulative particle size distribution for run 20

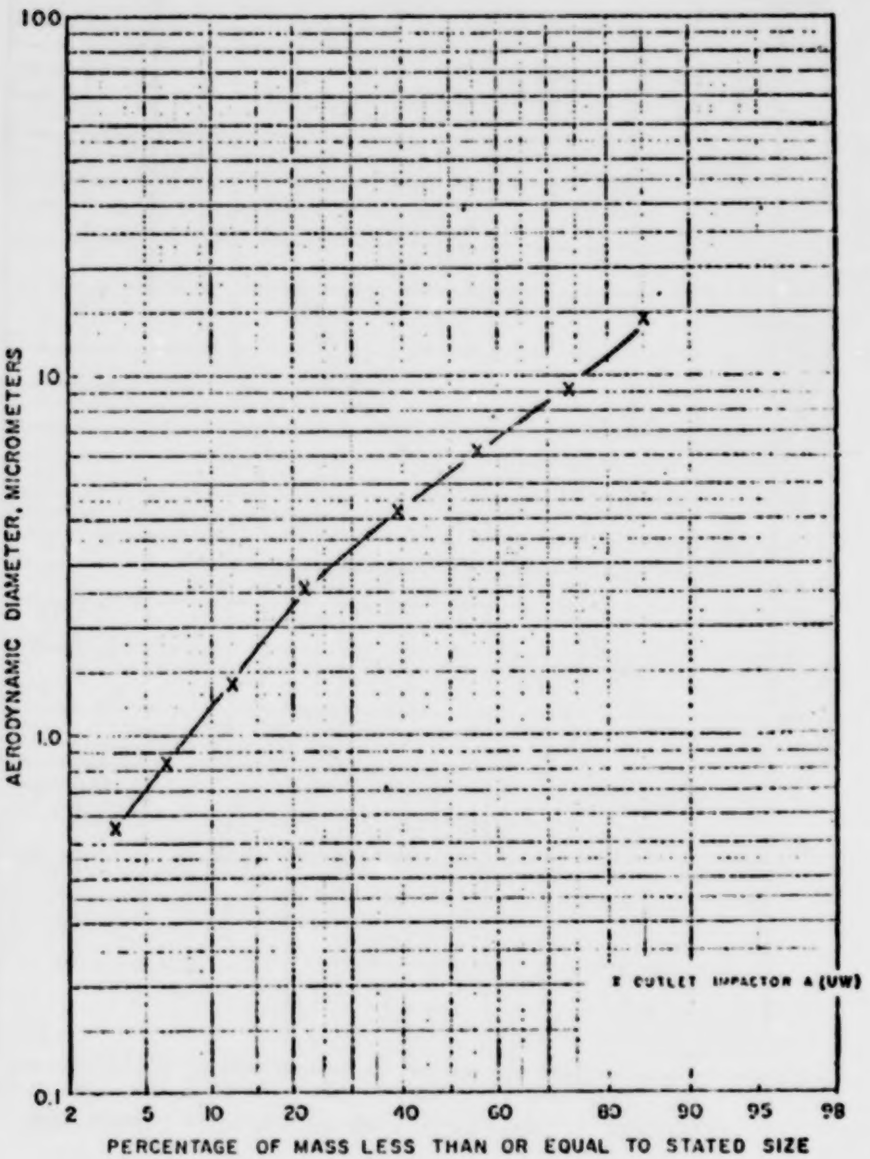


Figure 53. Outlet cumulative particle size distribution for run 20

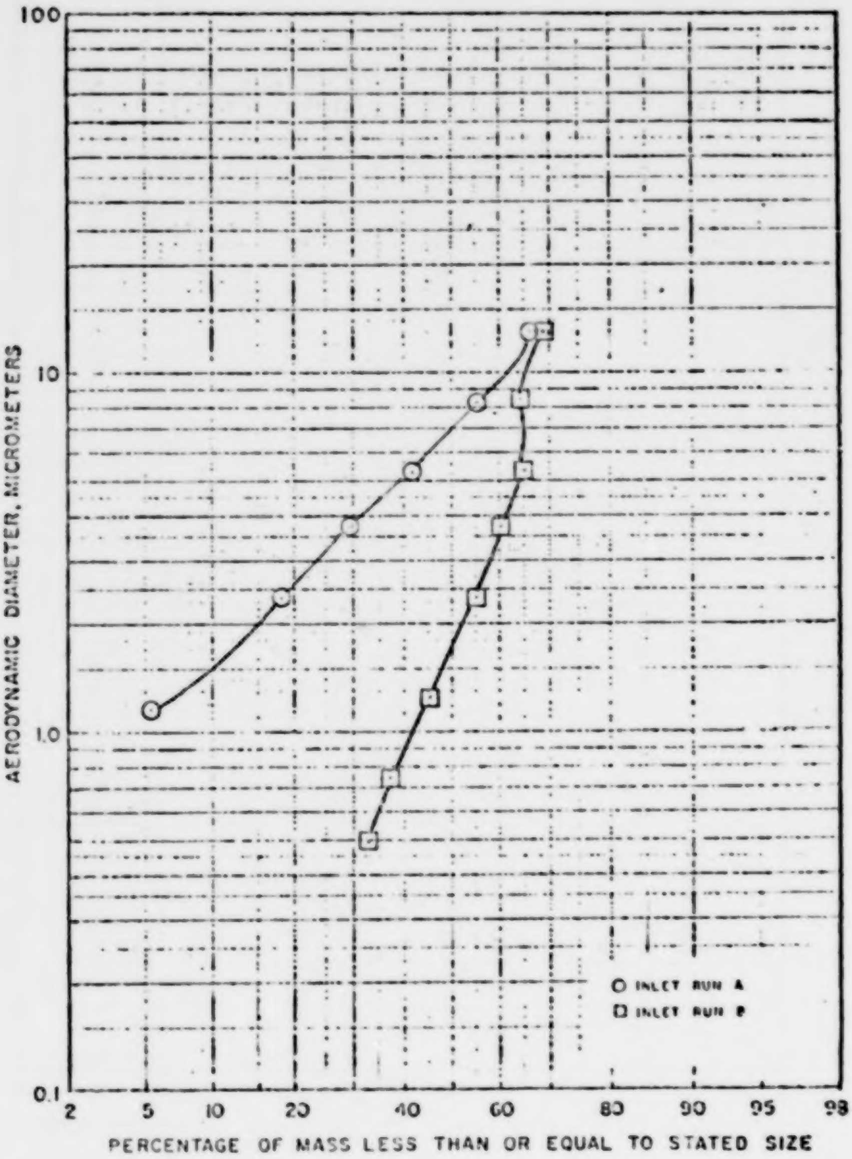


Figure 54. Inlet cumulative particle size distribution for run 21

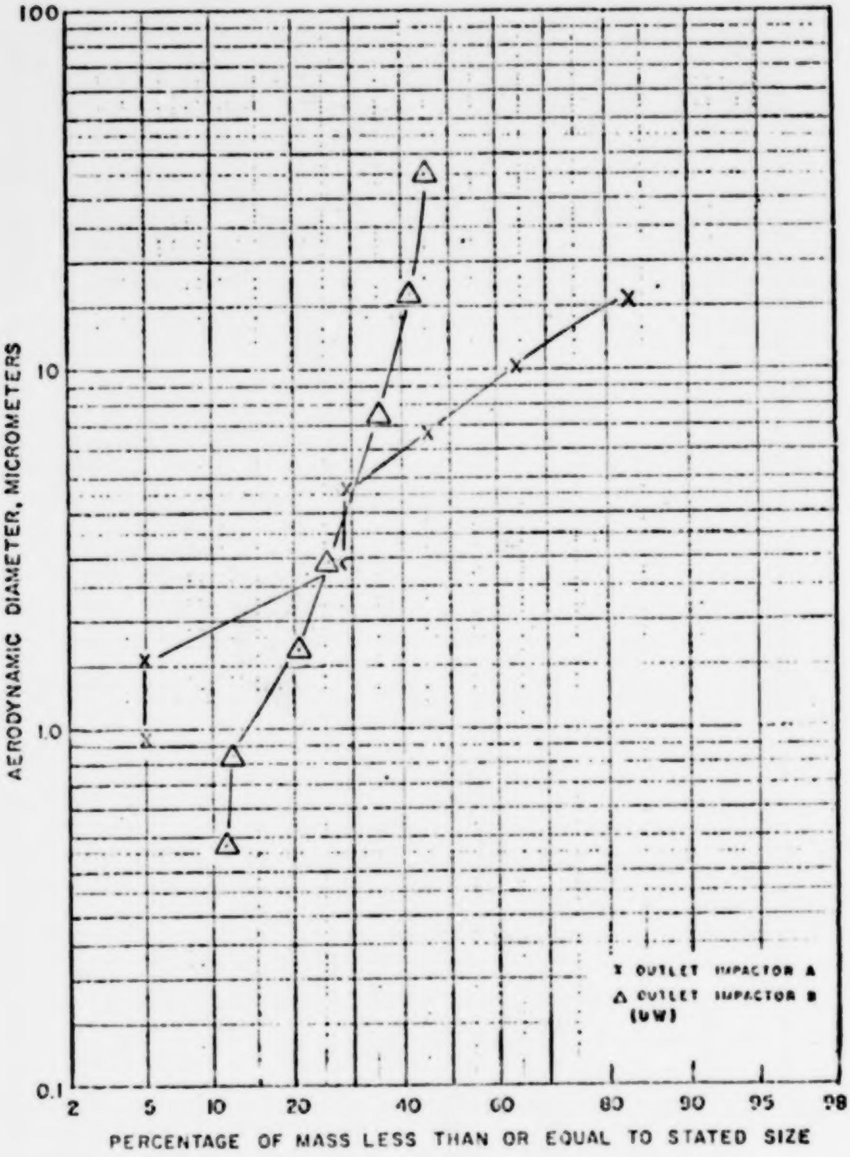


Figure 55. Outlet cumulative particle size distribution for run 21

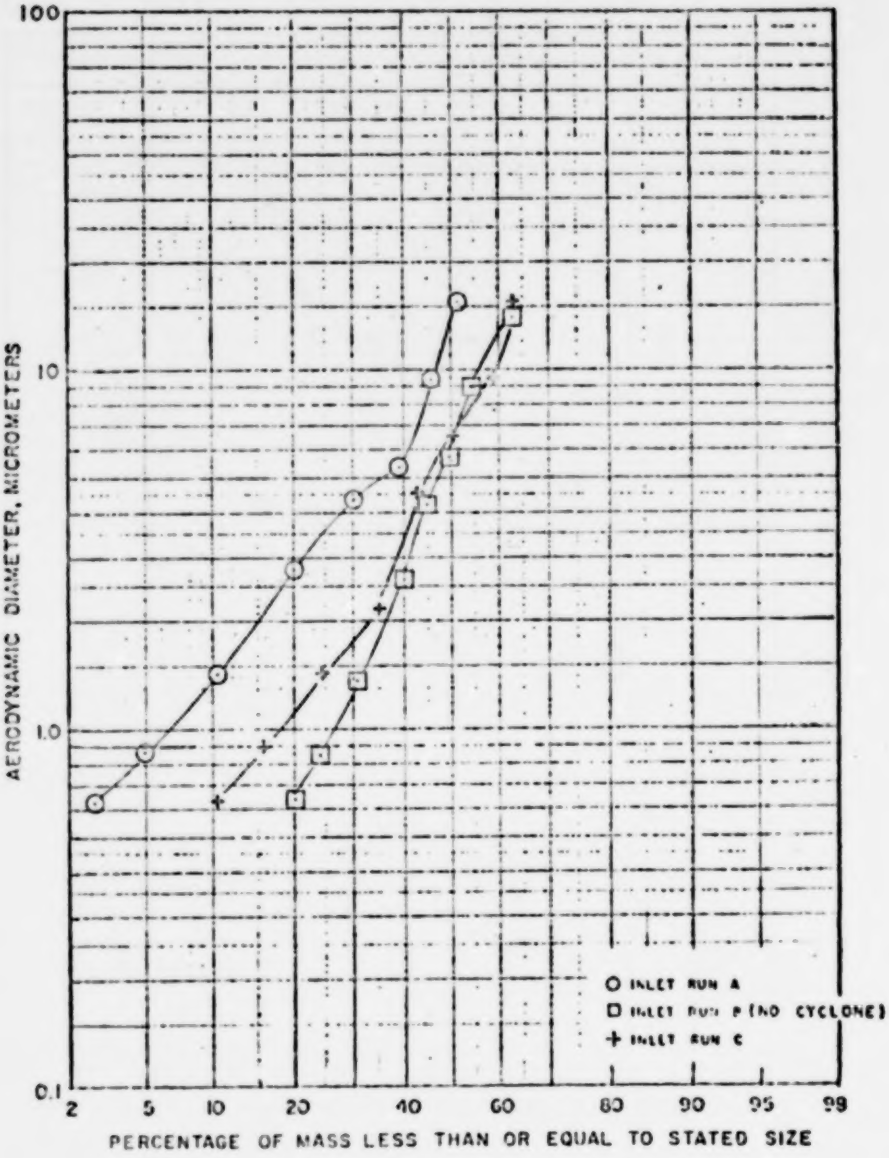


Figure 56. Inlet cumulative particle size distribution for run 22

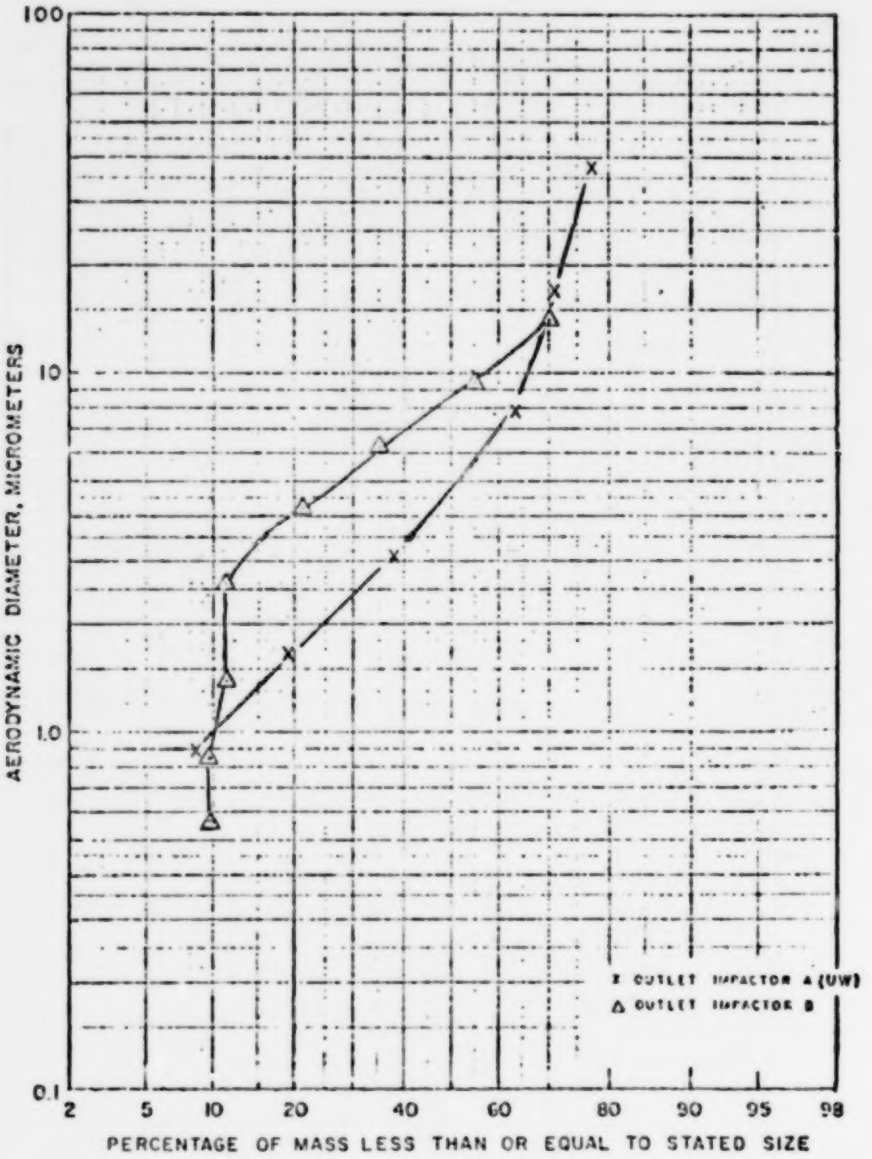


Figure 57. Outlet cumulative particle size distribution for run 22

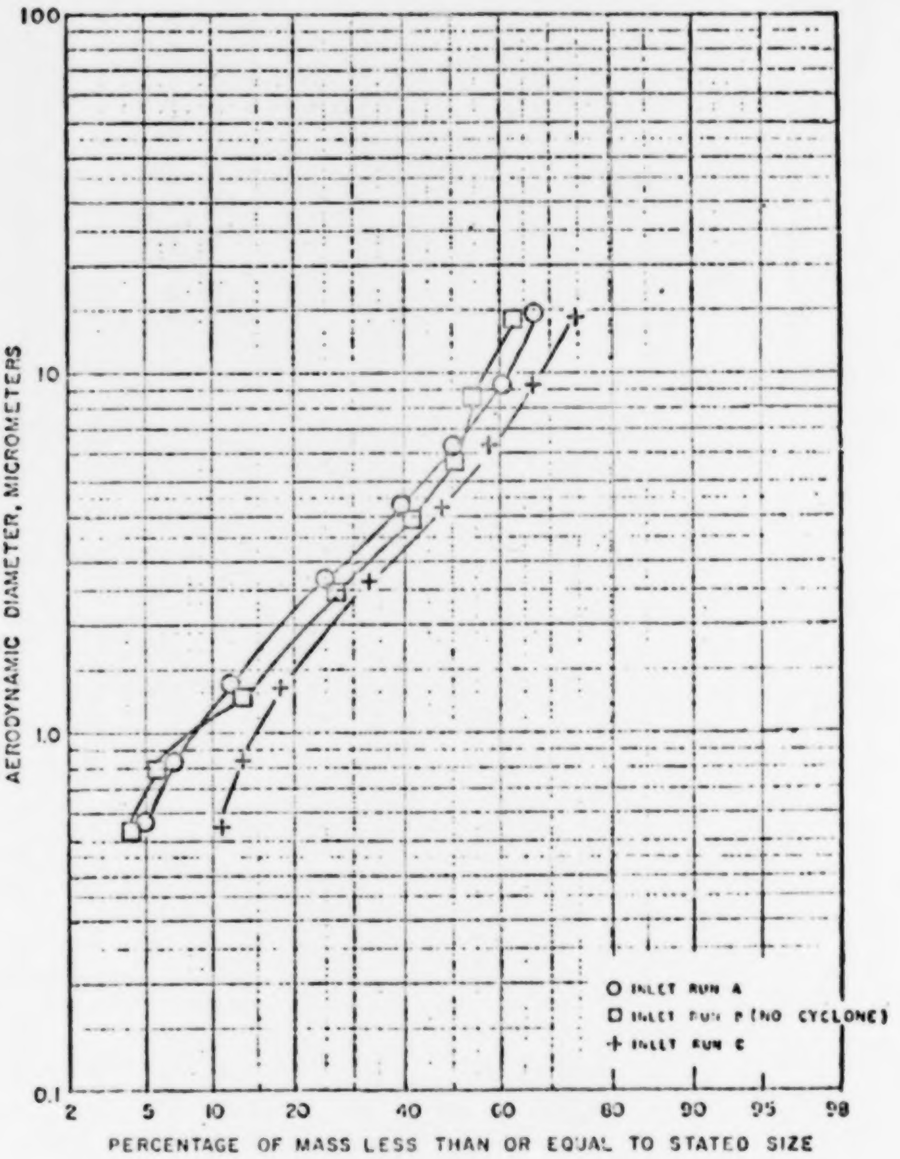


Figure 58. Inlet cumulative particle size distribution for run 23

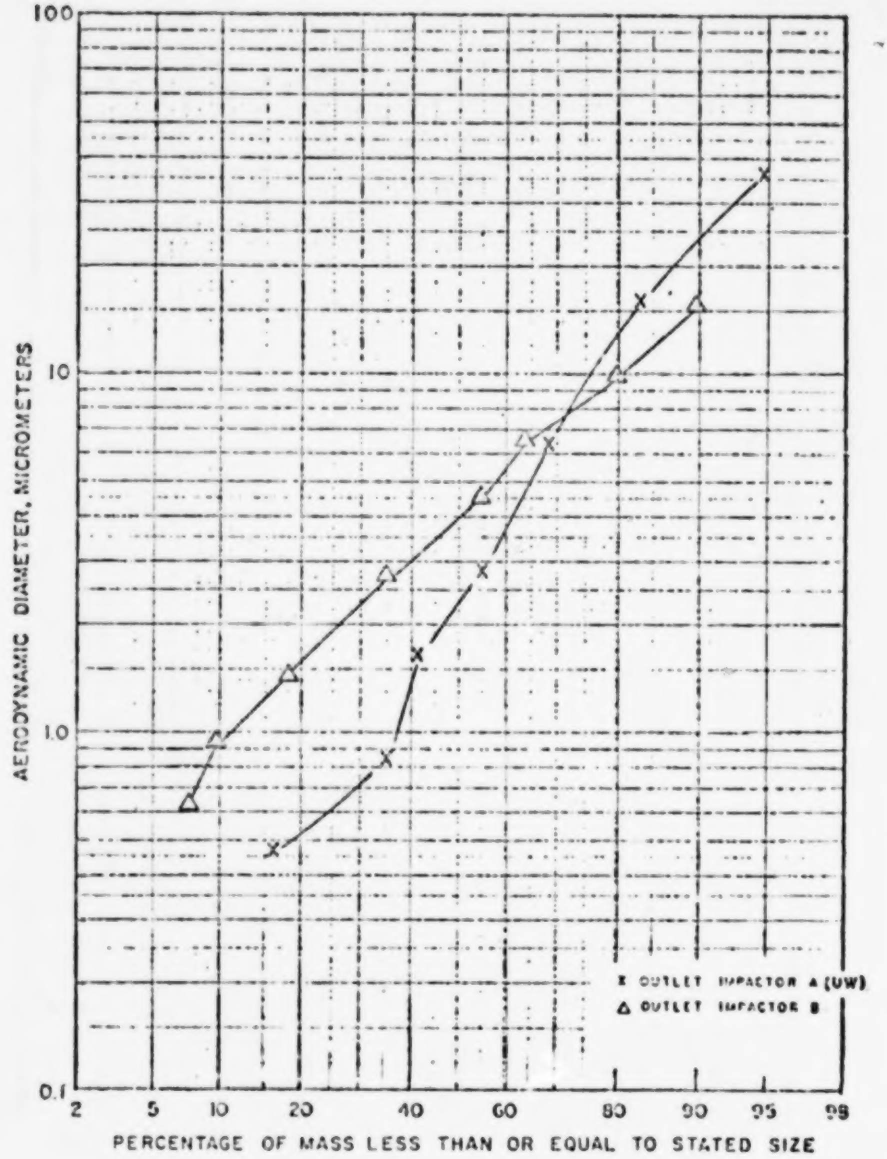


Figure 59. Outlet cumulative particle size distribution for run 23

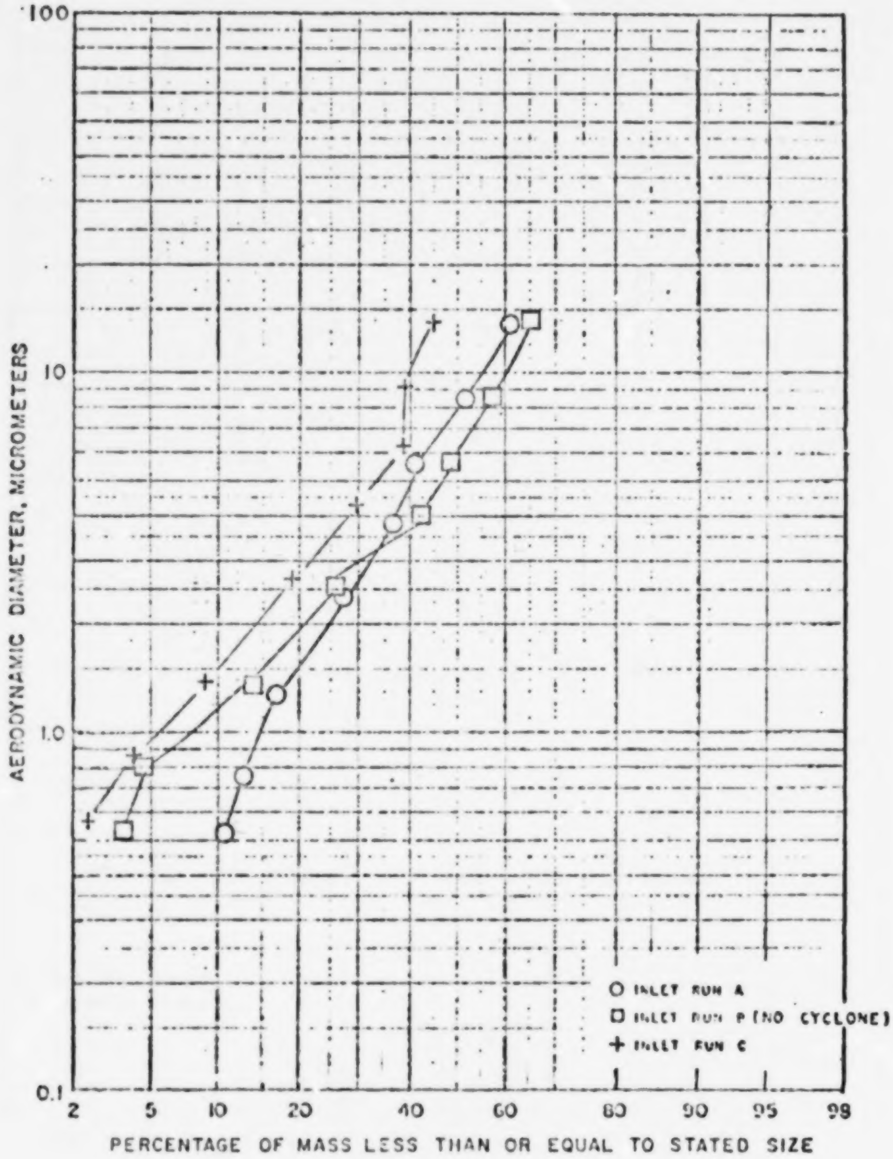


Figure 60. Inlet cumulative particle size distribution for run 24

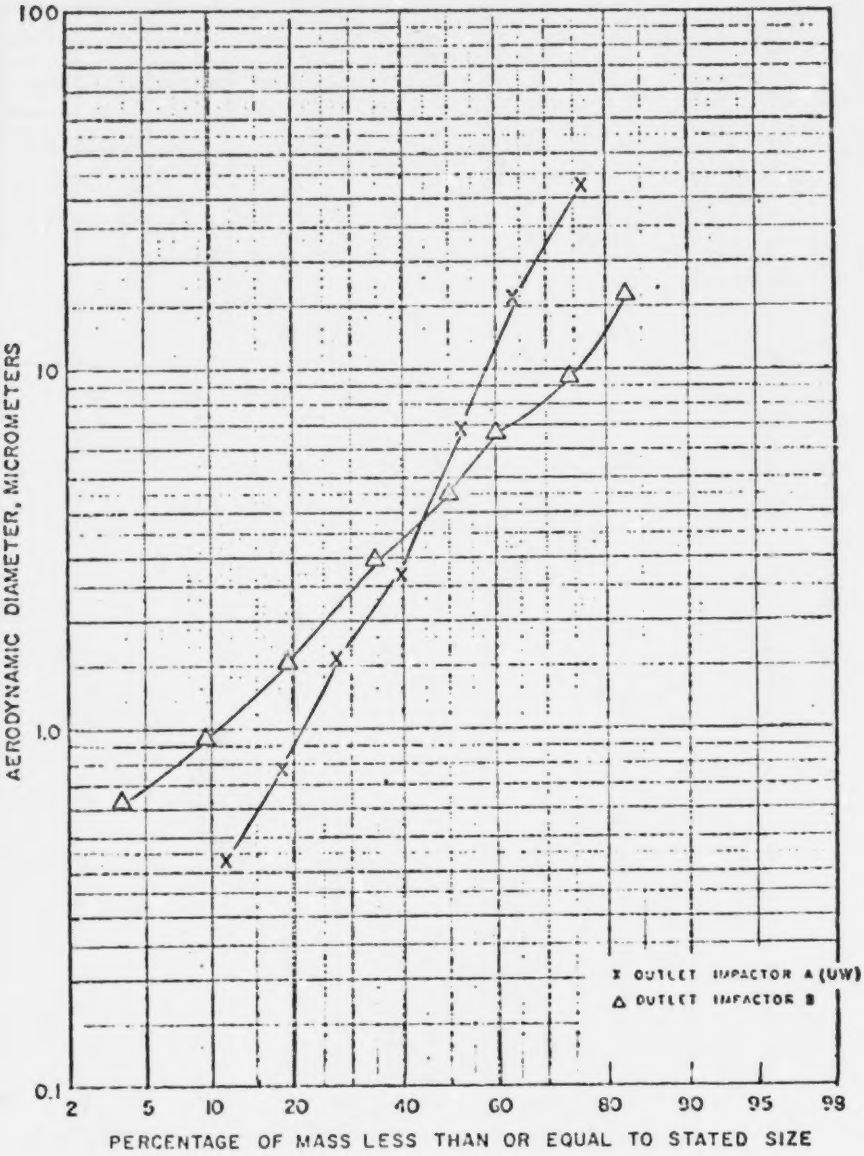


Figure 61. Outlet cumulative particle size distribution for run 24

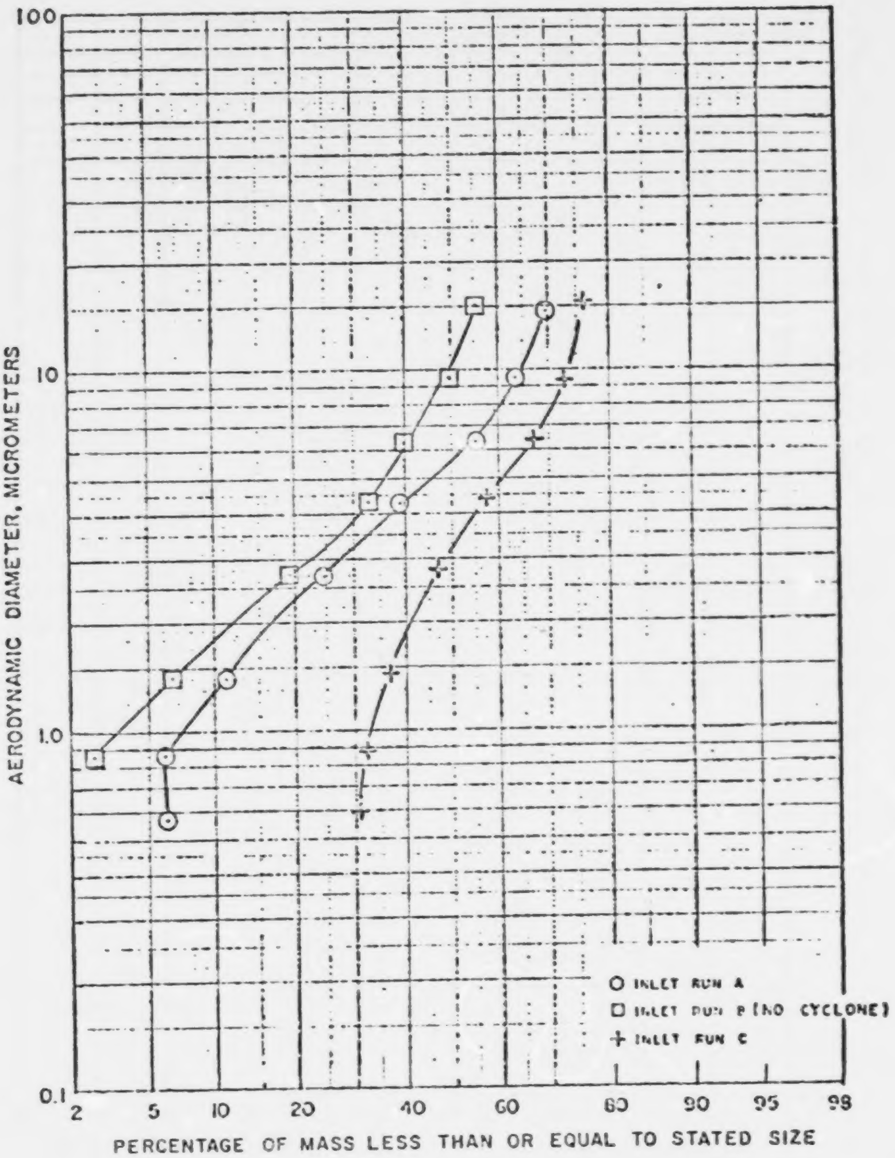


Figure 62. Inlet cumulative particle size distribution for run 25

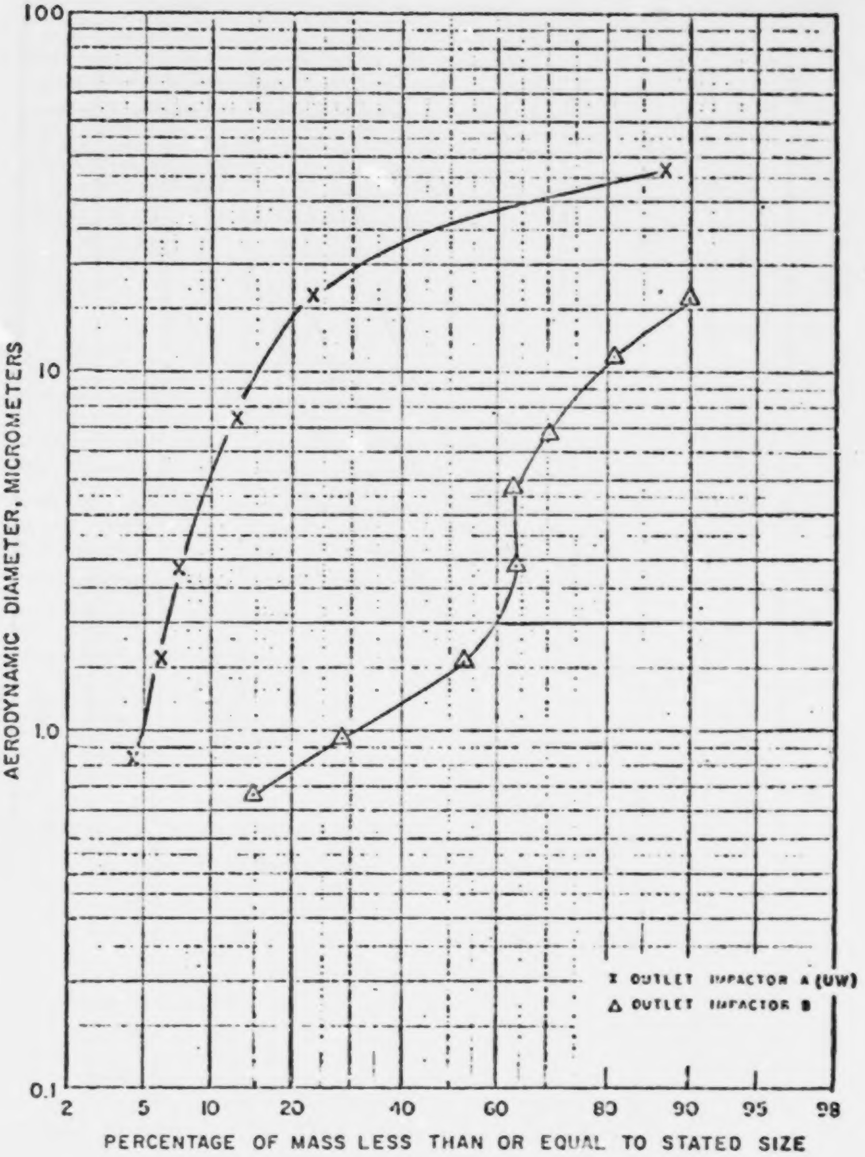


Figure 63. Outlet cumulative particle size distribution for run 25

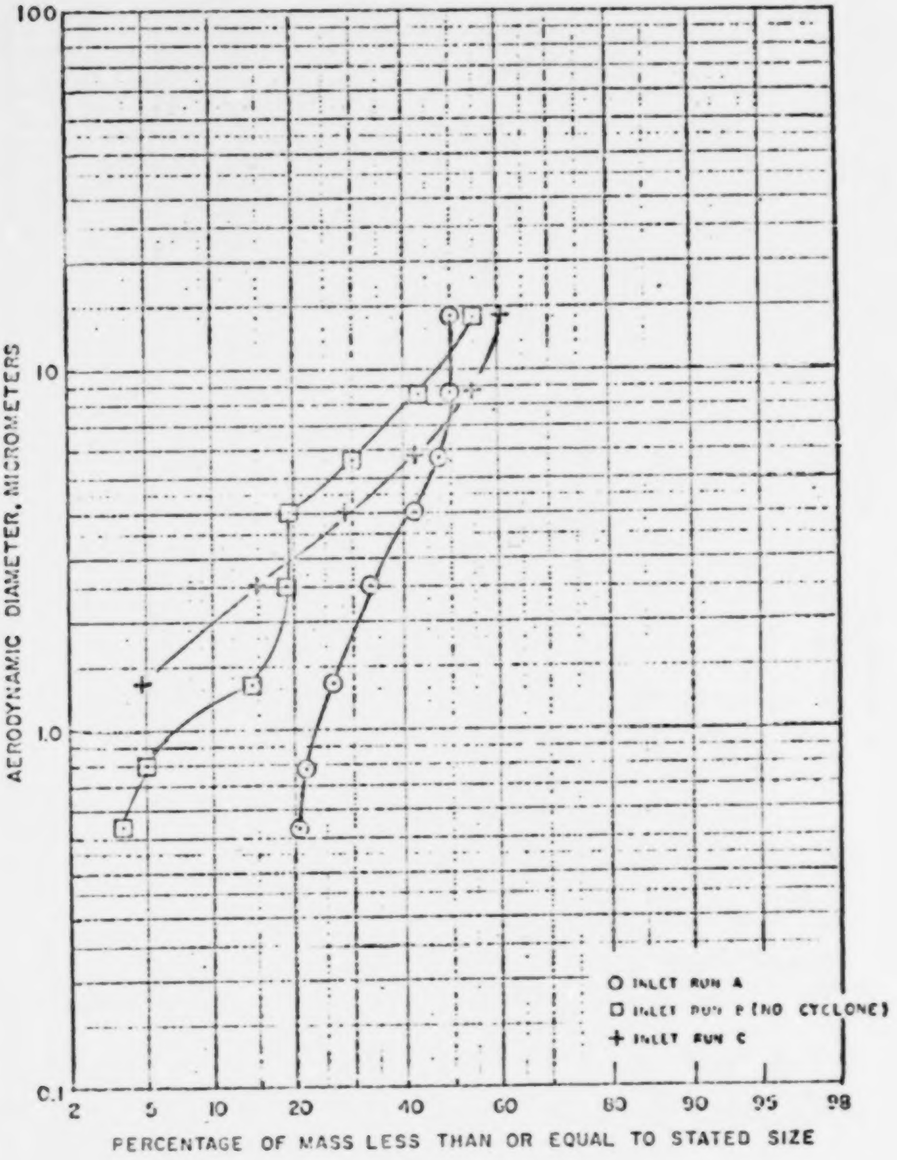


Figure 64. Inlet cumulative particle size distribution for run 26

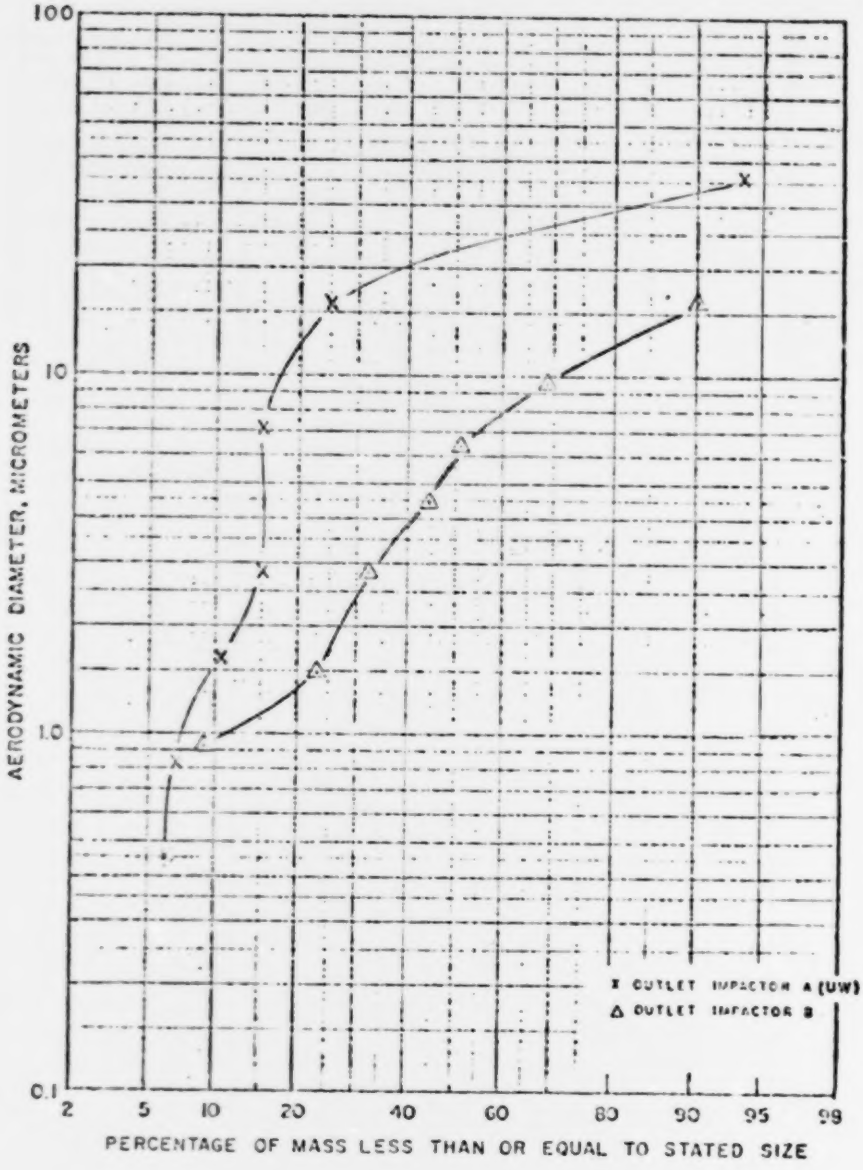


Figure 65. Outlet cumulative particle size distribution for run 26

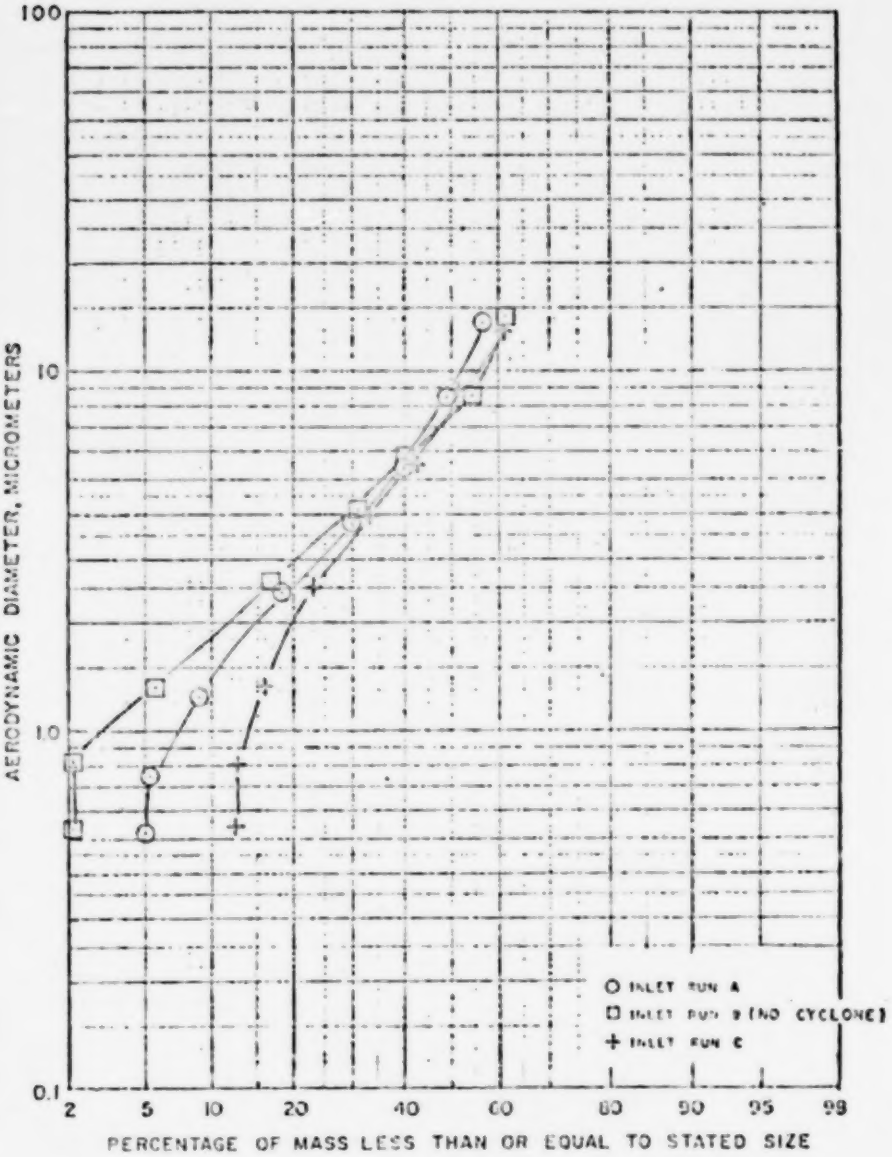


Figure 66. Inlet cumulative particle size distribution for run 27

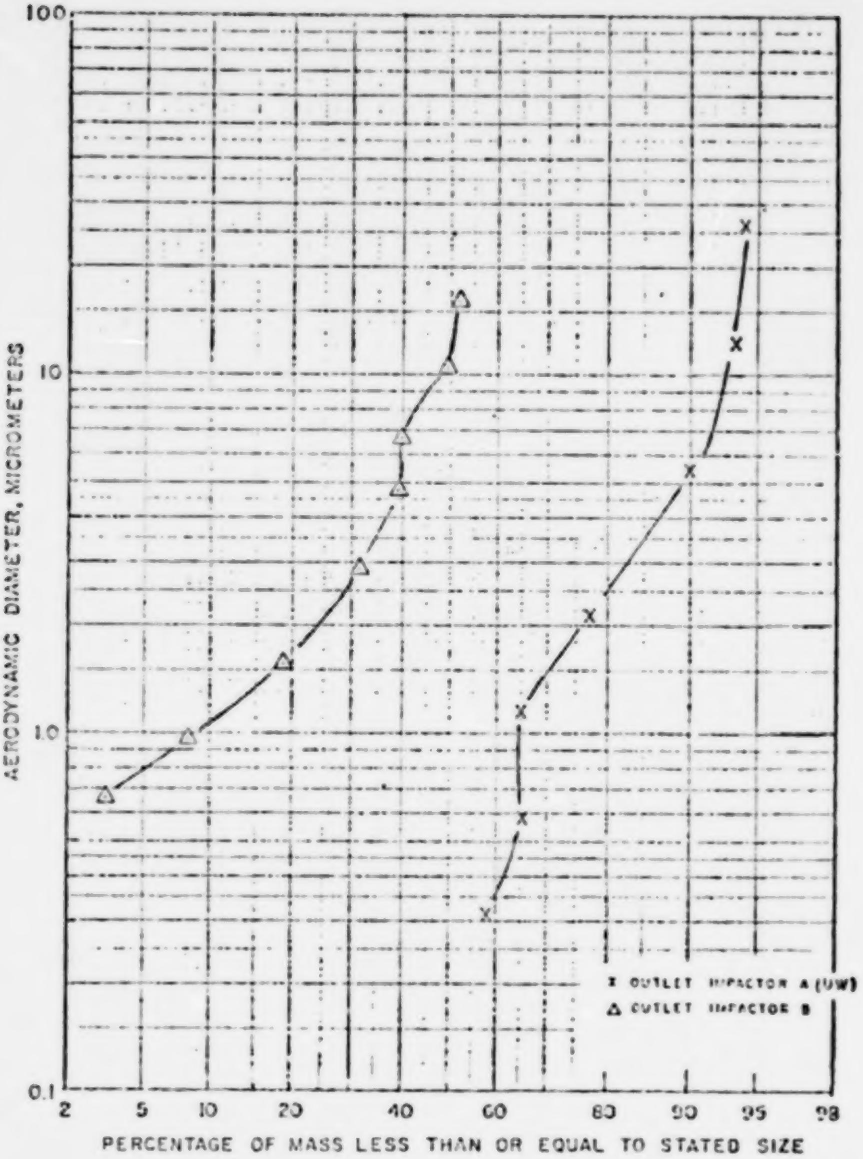


Figure 67. Outlet cumulative particle size distribution for run 27

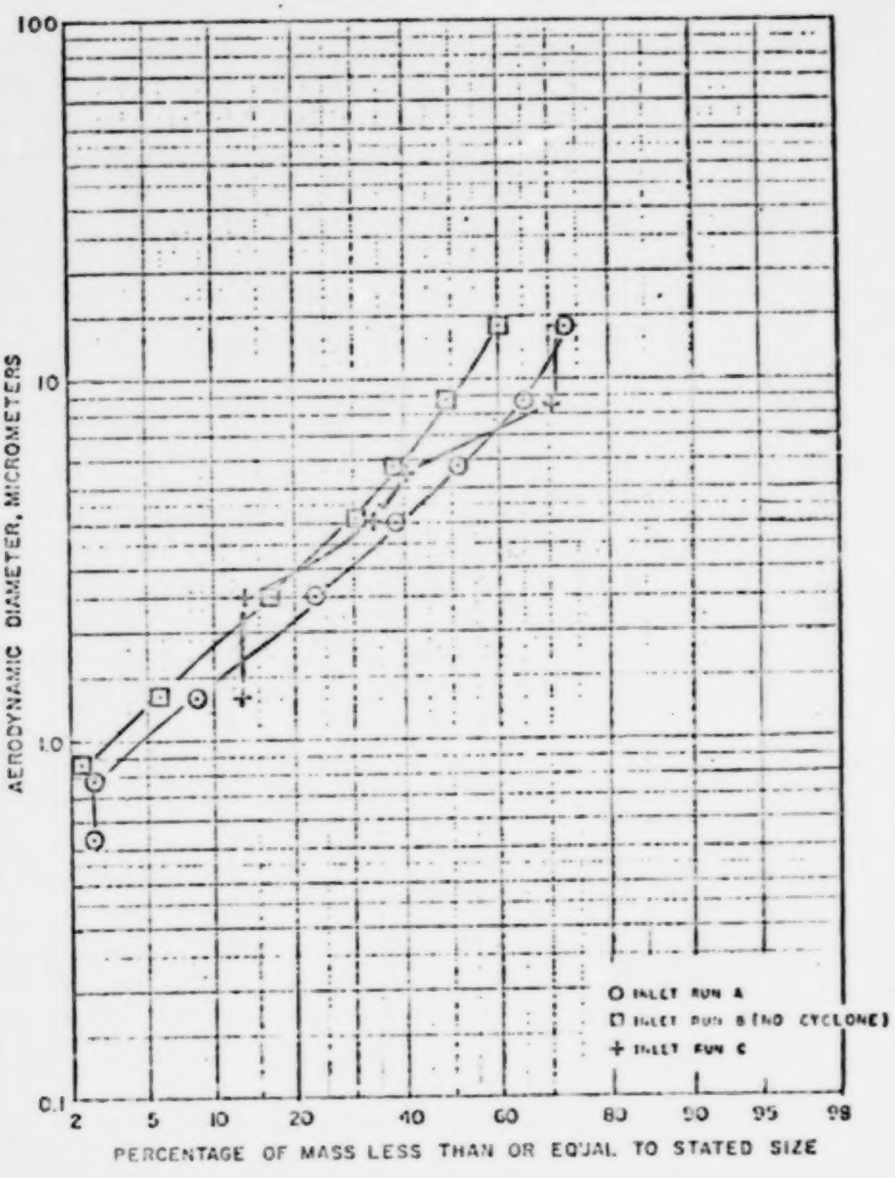


Figure 68. Inlet cumulative particle size distribution for run 28

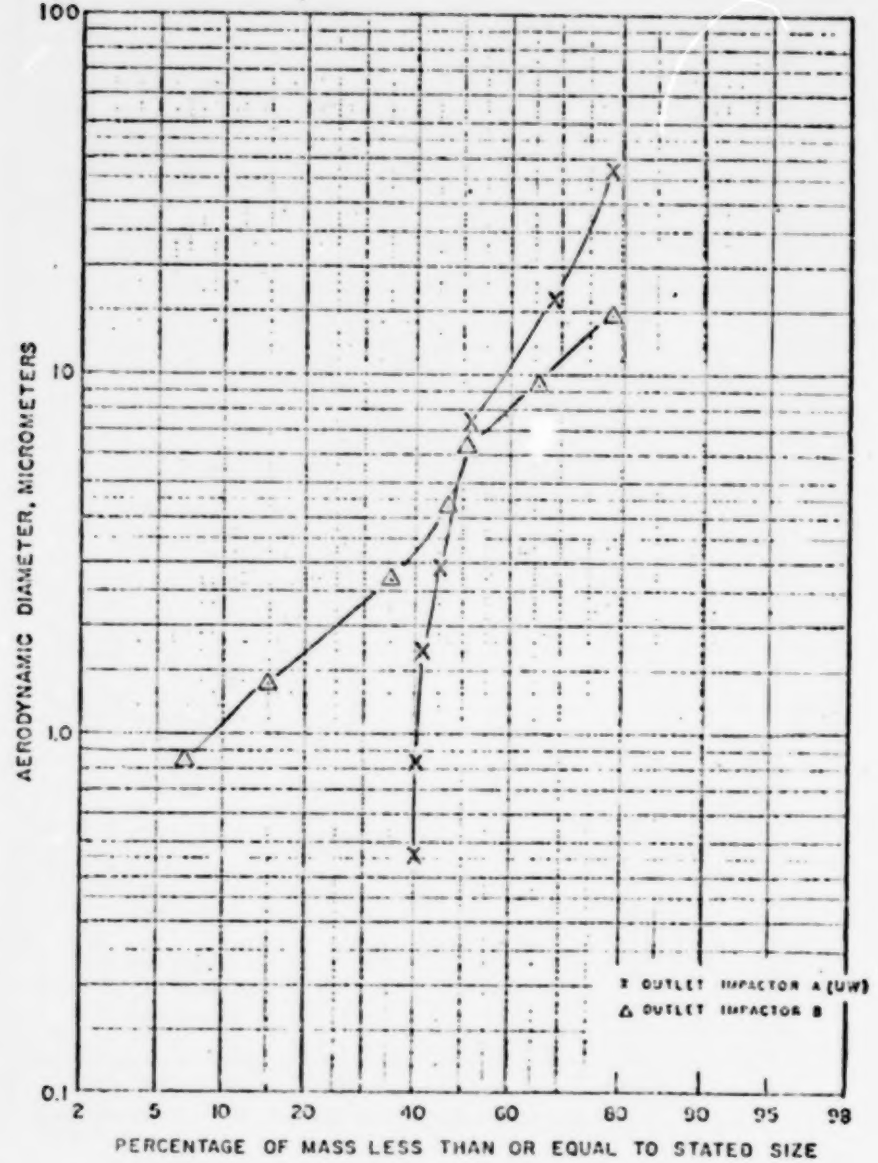


Figure 69. Outlet cumulative particle size distribution for run 28

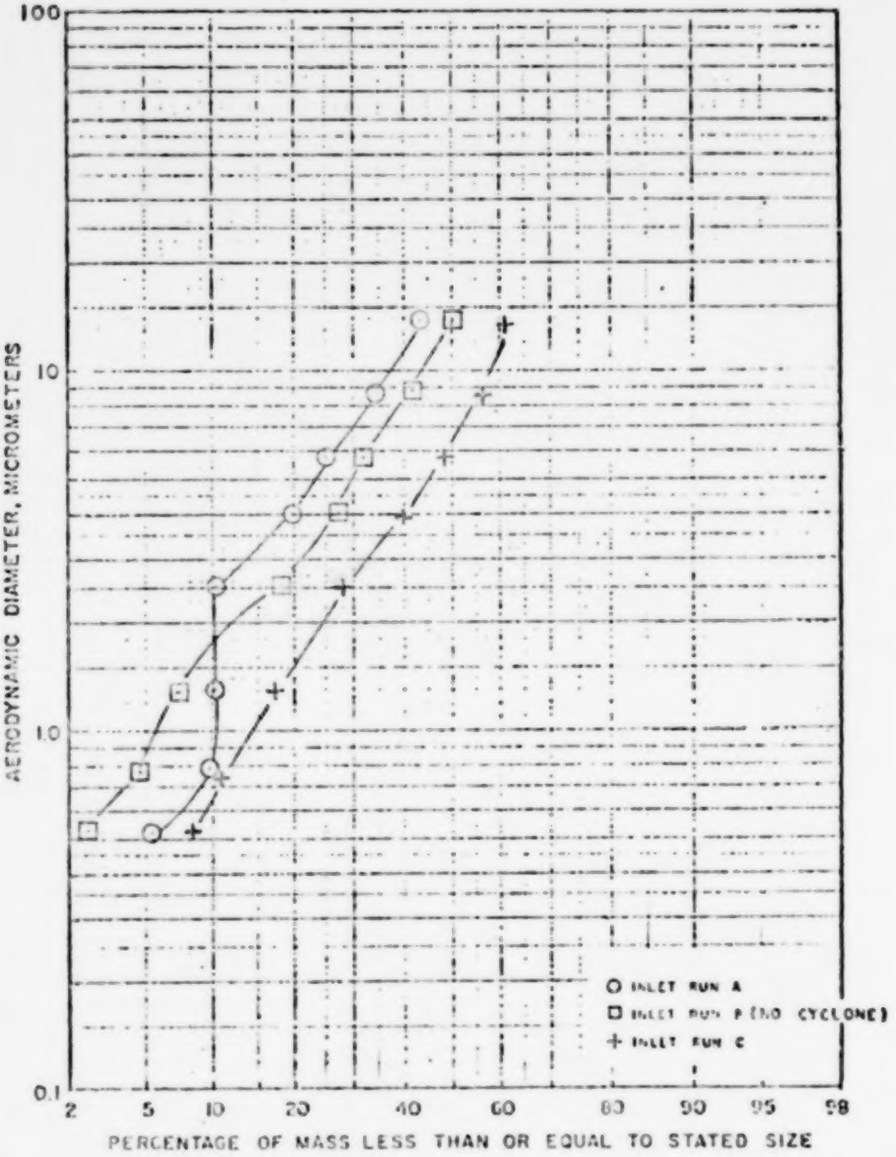


Figure 70. Inlet cumulative particle size distribution for run 29

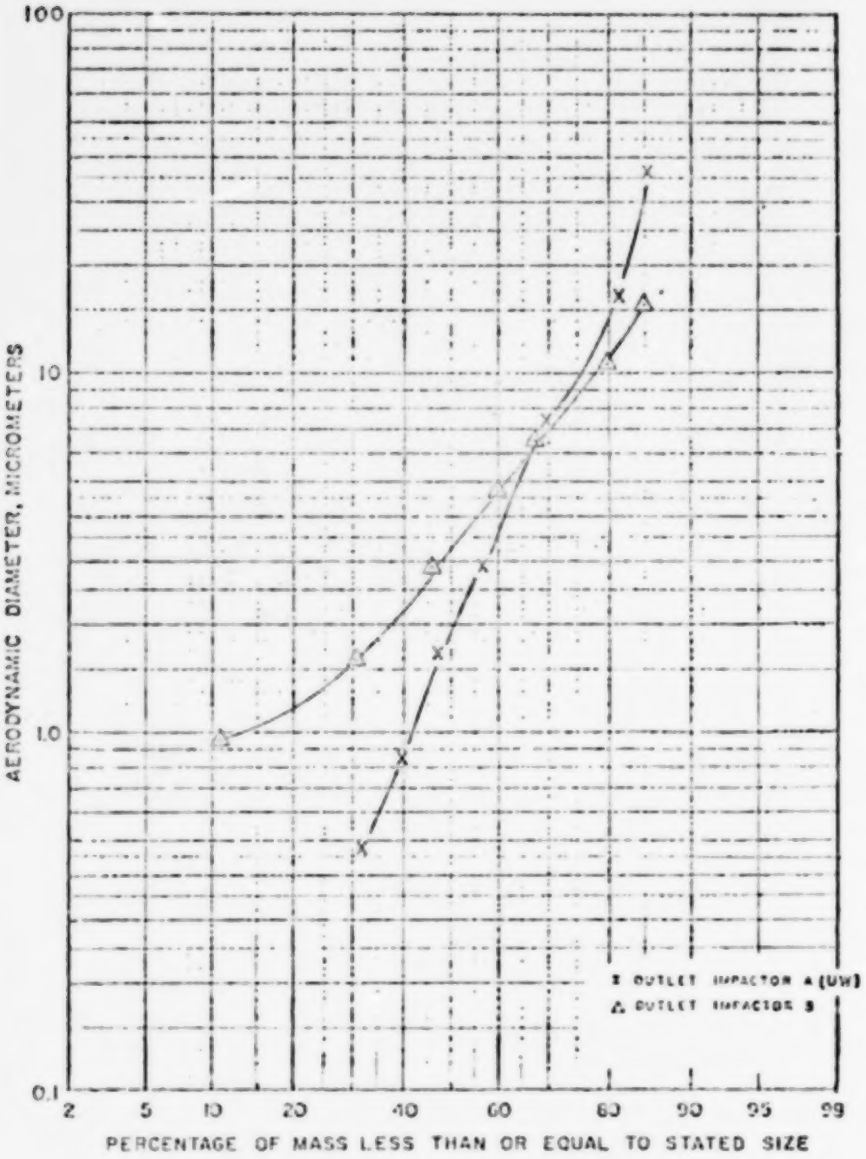


Figure 71. Outlet cumulative particle size distribution for run 29

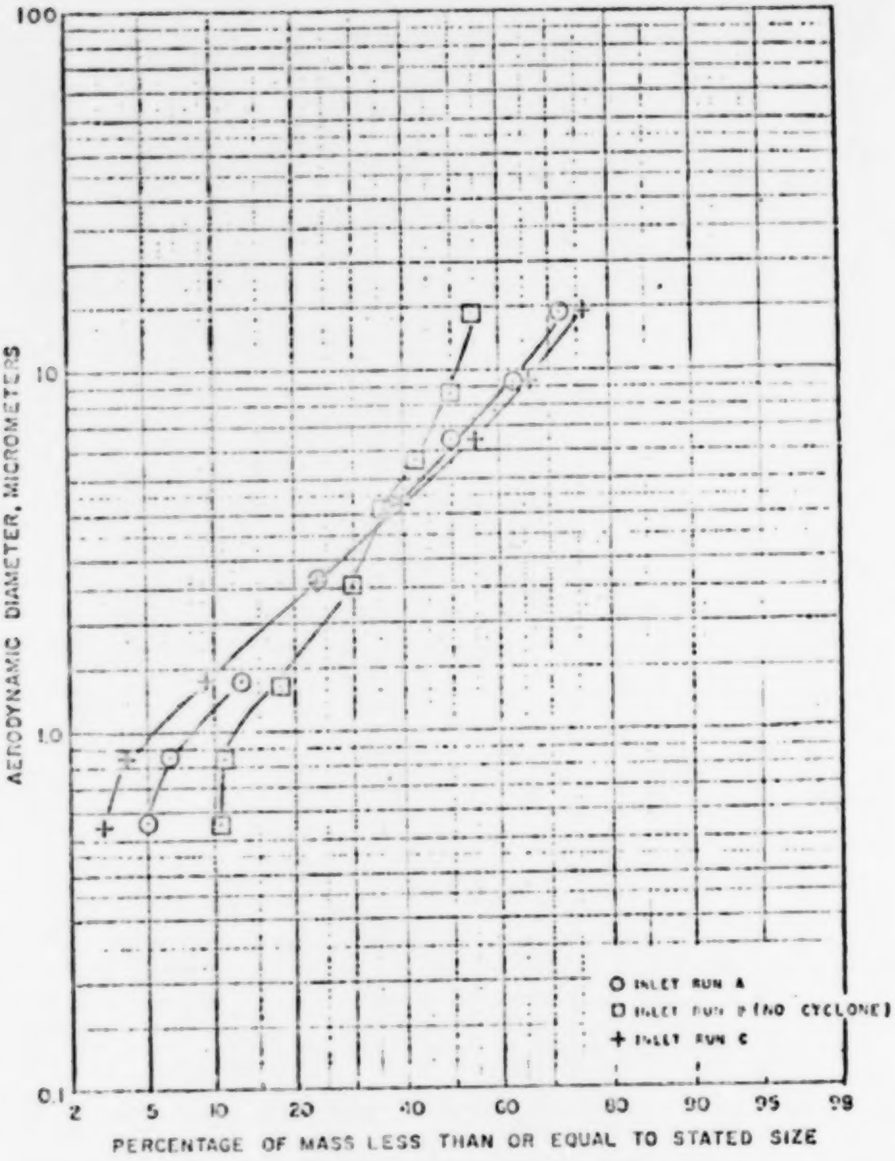


Figure 72. Inlet cumulative particle size distribution for run 30

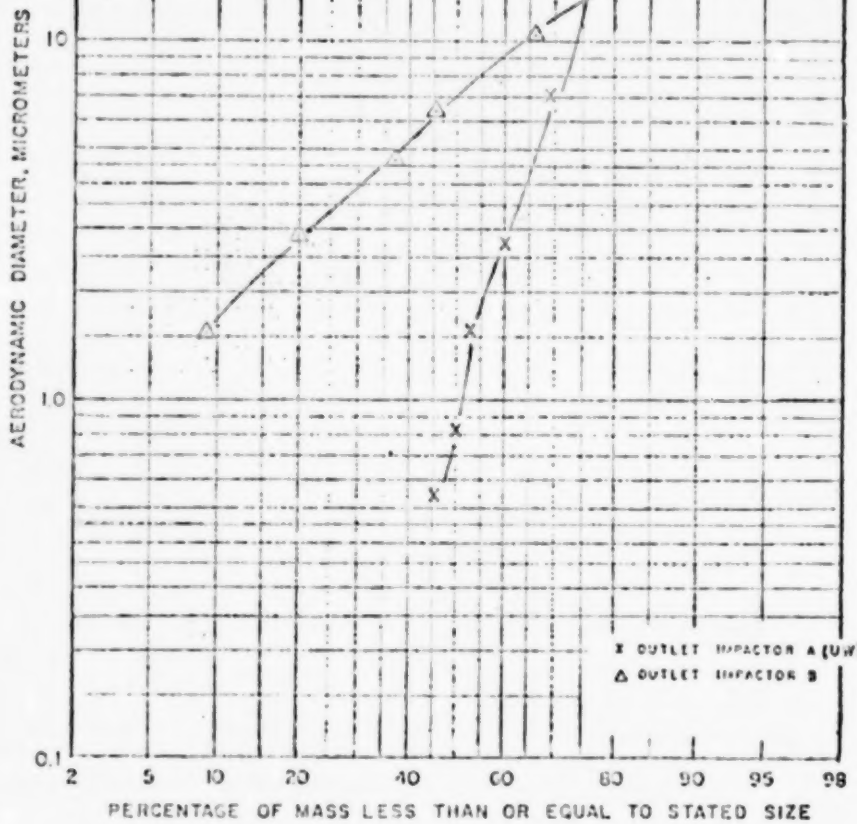


Figure 73. Outlet cumulative particle size distribution for run 30

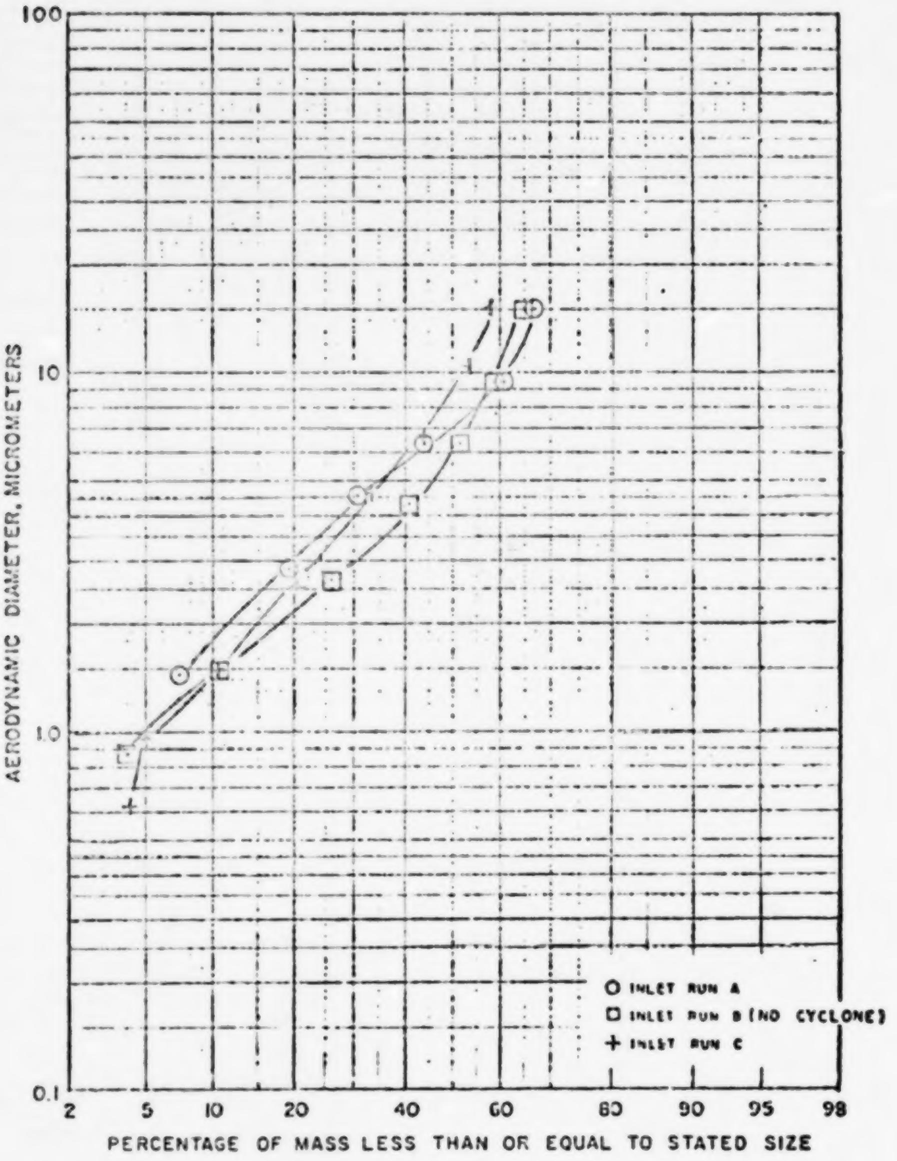


Figure 74. Inlet cumulative particle size distribution for run 31

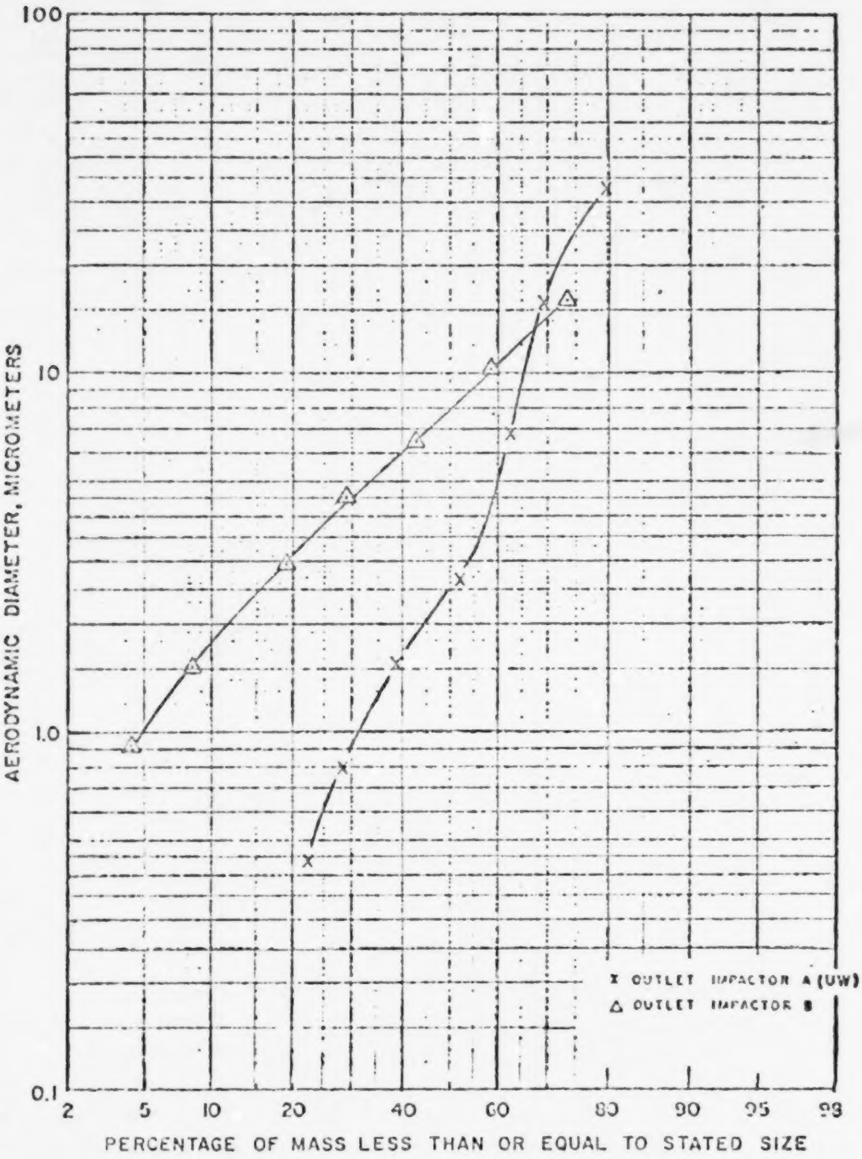
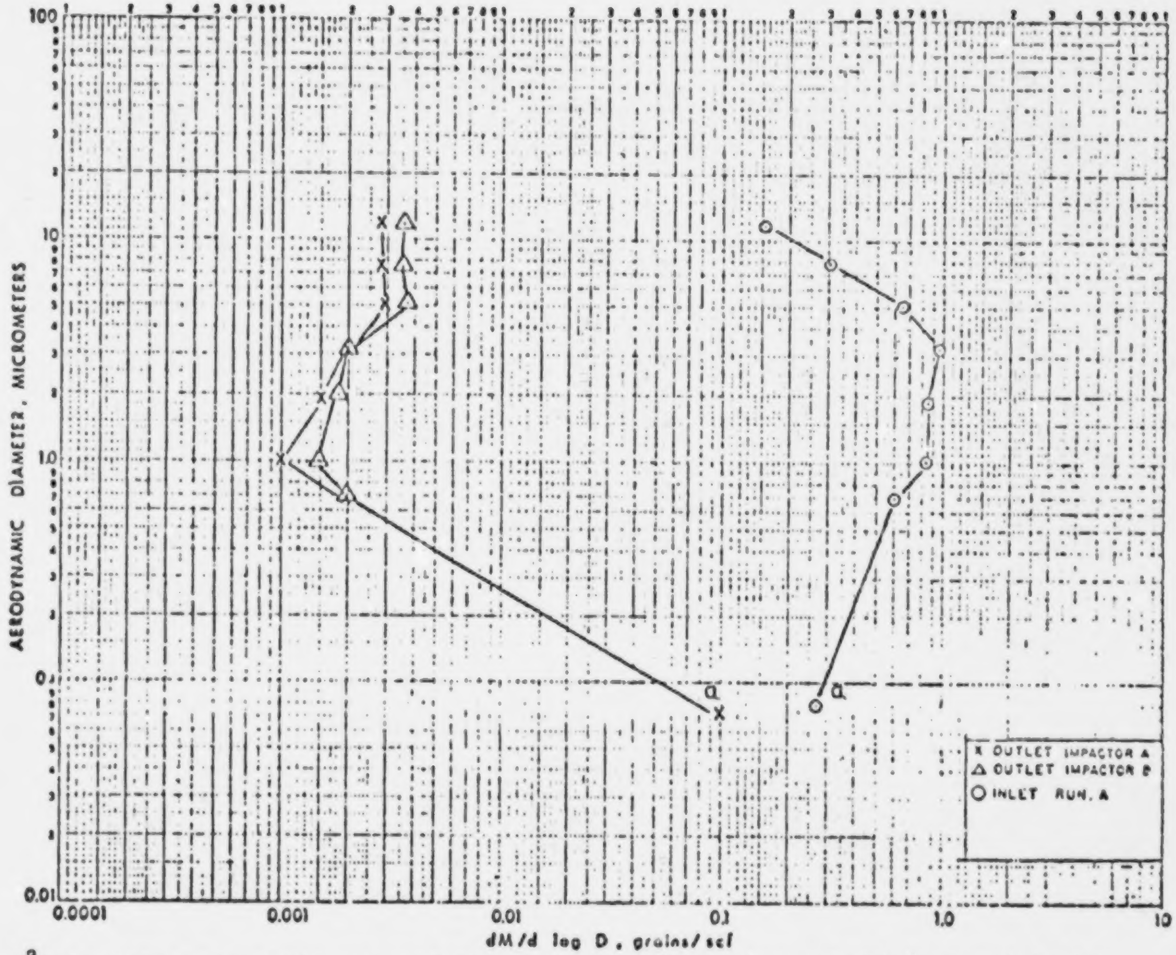


Figure 75. Outlet cumulative particle size distribution for run 31

APPENDIX B

DIFFERENTIAL SIZE DISTRIBUTION CURVES



[a] Calculated geometric mean of the back up filter size cutoff (assumed to be 0.01 µm) and the size cutoff of the last impactor stage.

Figure 76. Differential particle size distribution for run 1

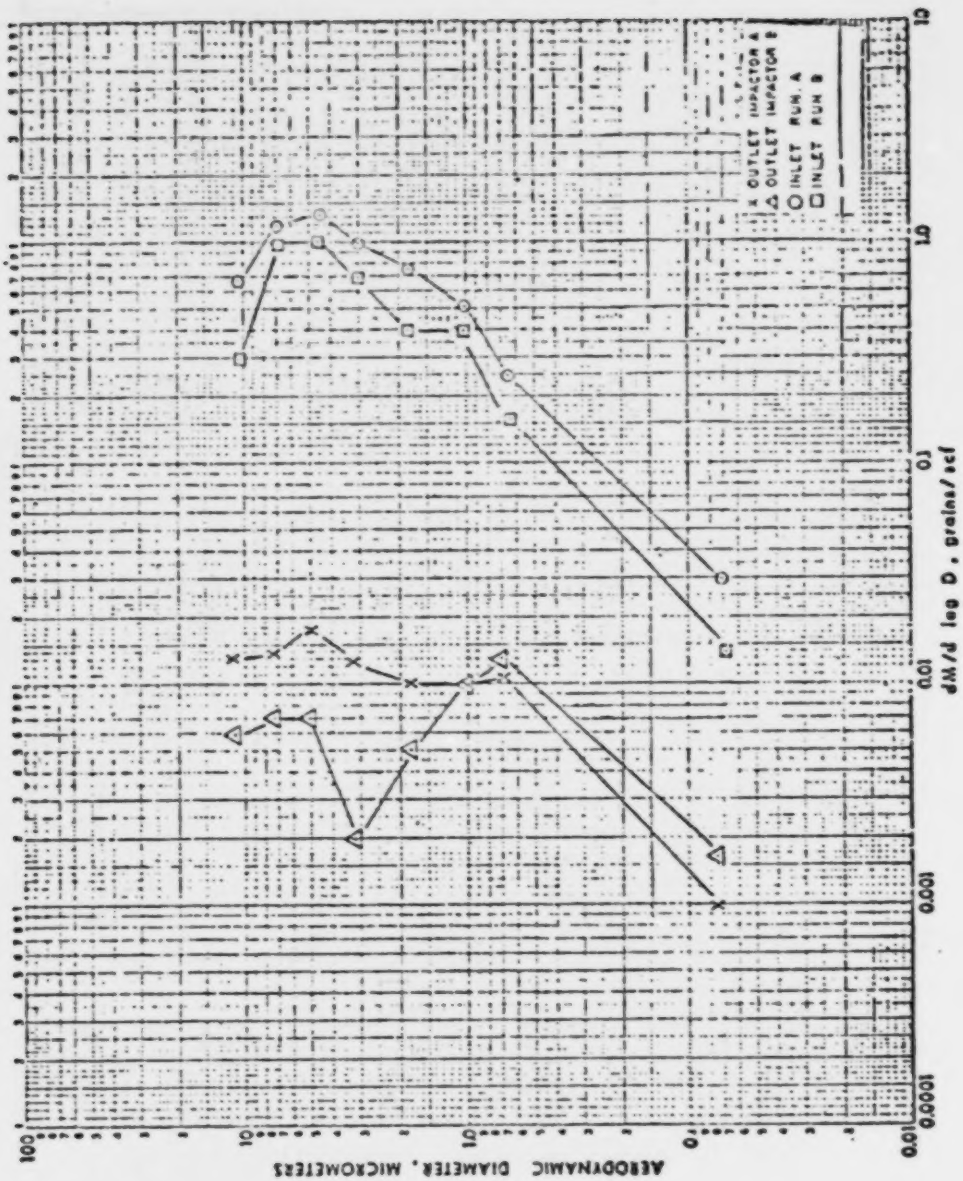


Figure 77. Differential particle size distribution for run 2

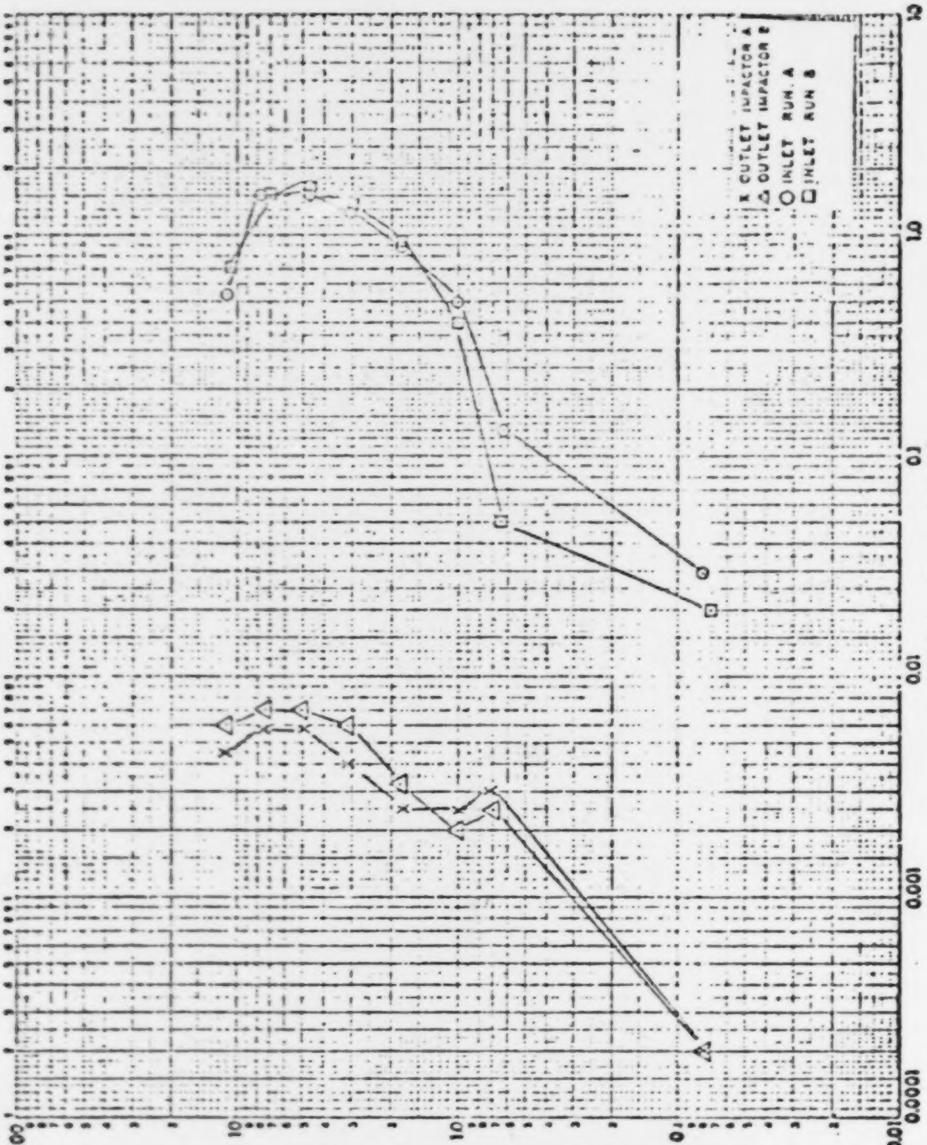


Figure 78. Differential particle size distribution for run 3

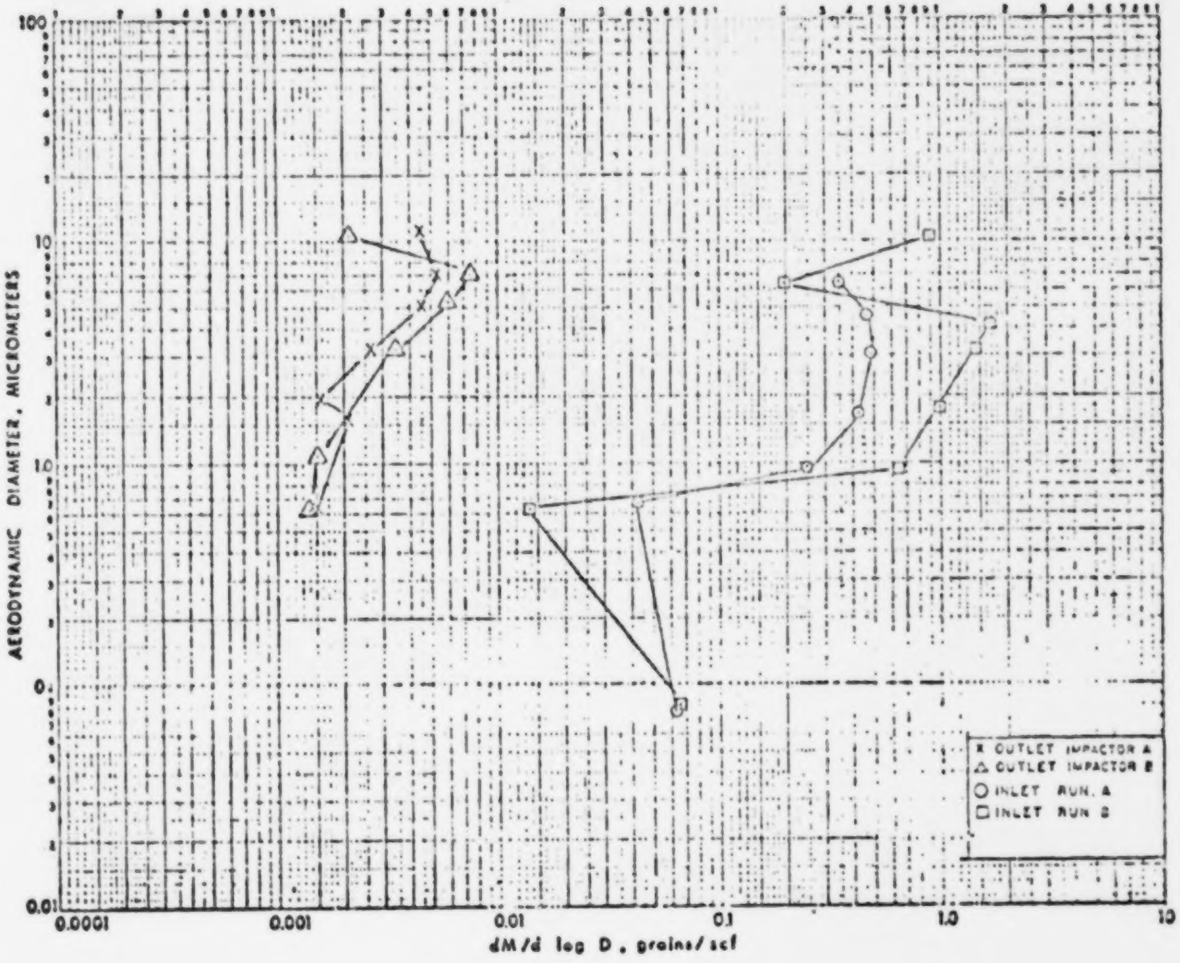


Figure 79. Differential particle size distribution for run 4

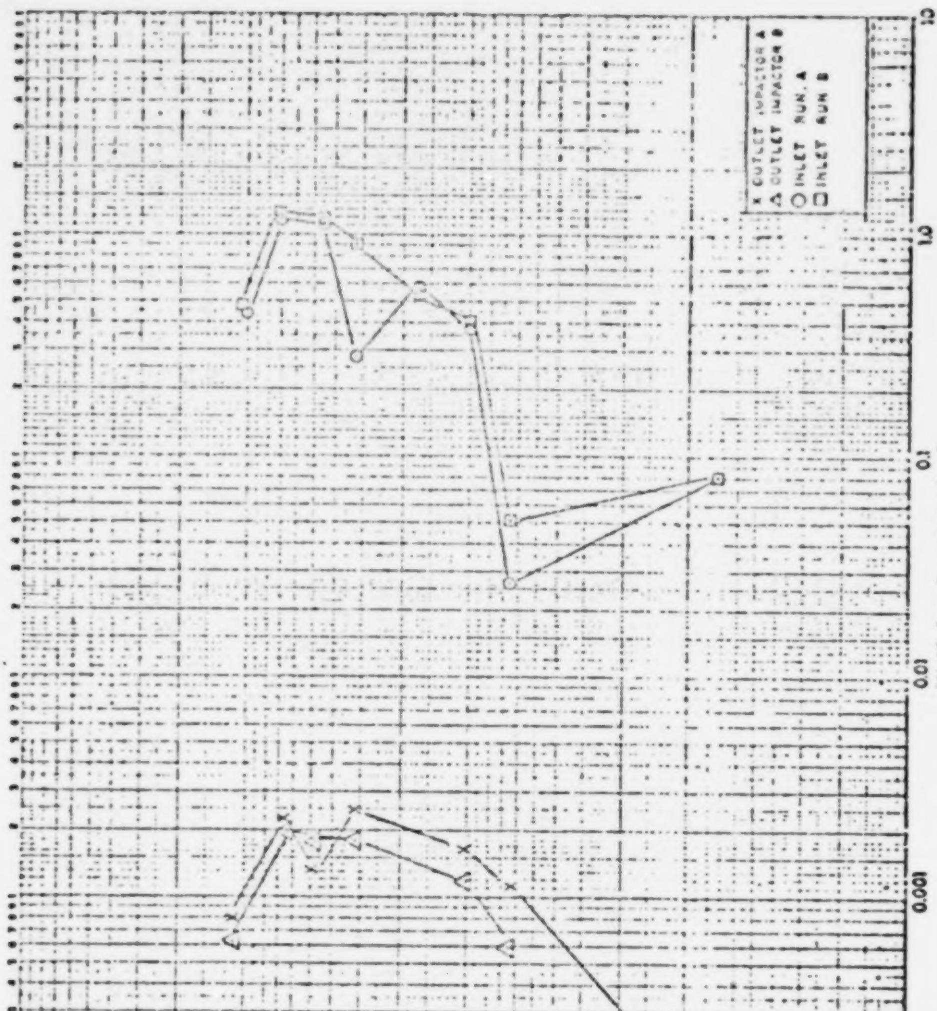


Figure 80. Differential particle size distribution for run 5

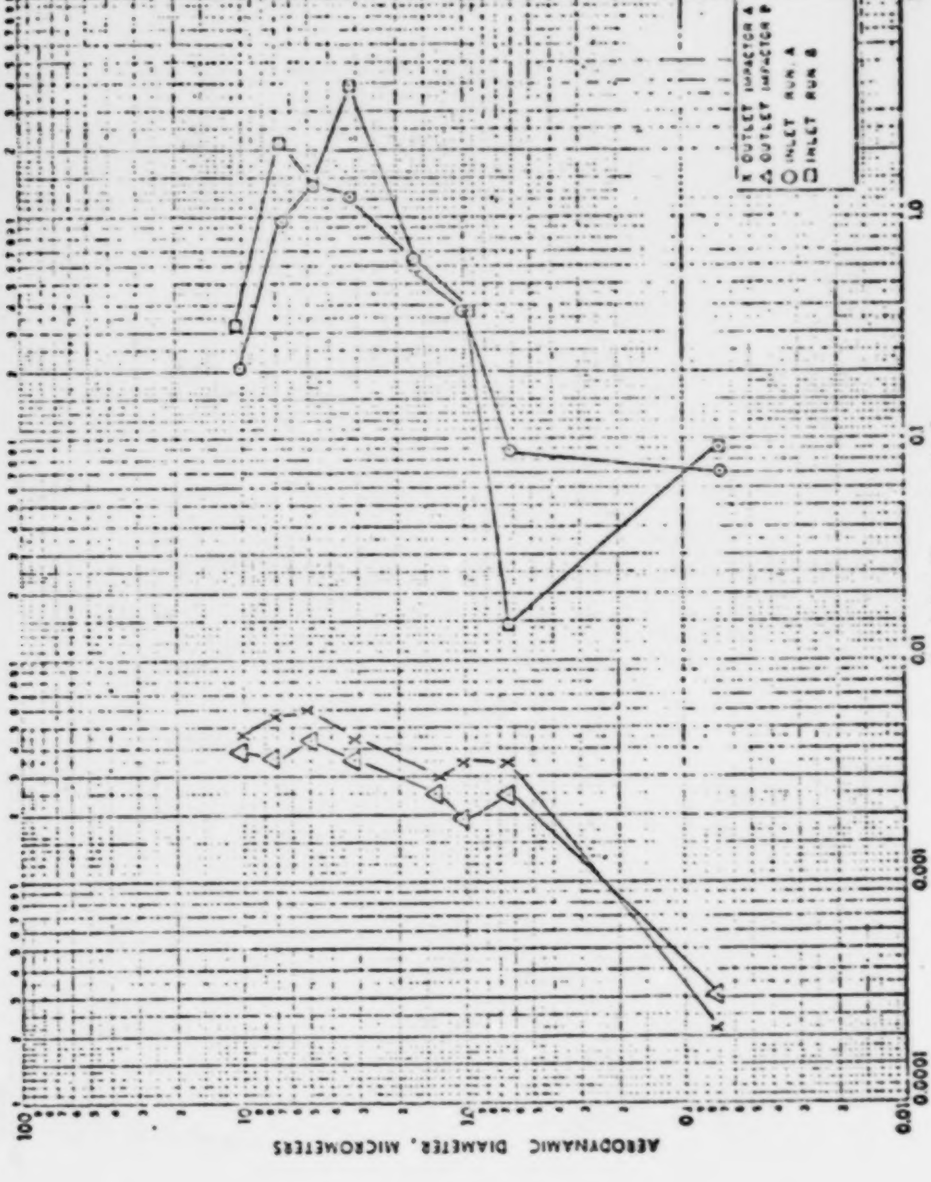


Figure 81. Differential particle size distribution for run 6

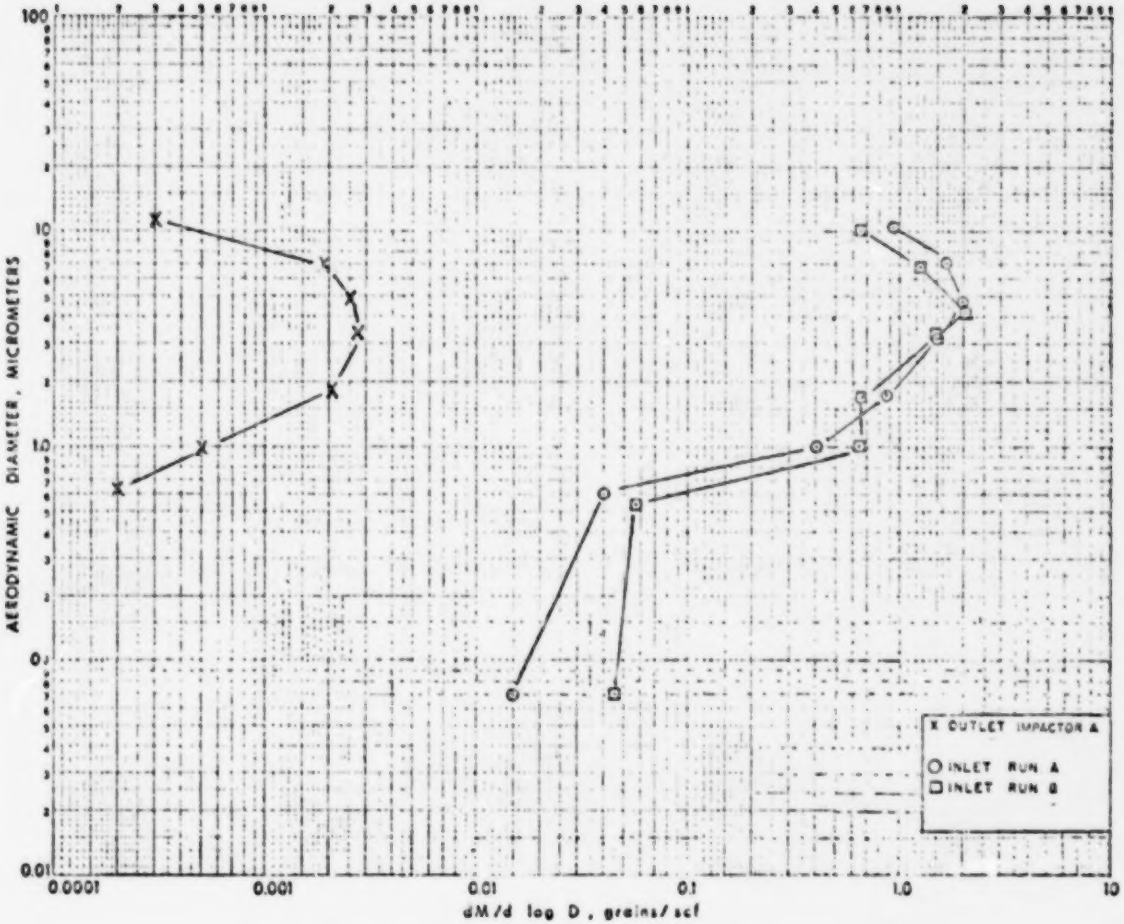


Figure 82. Differential particle size distribution for run 7

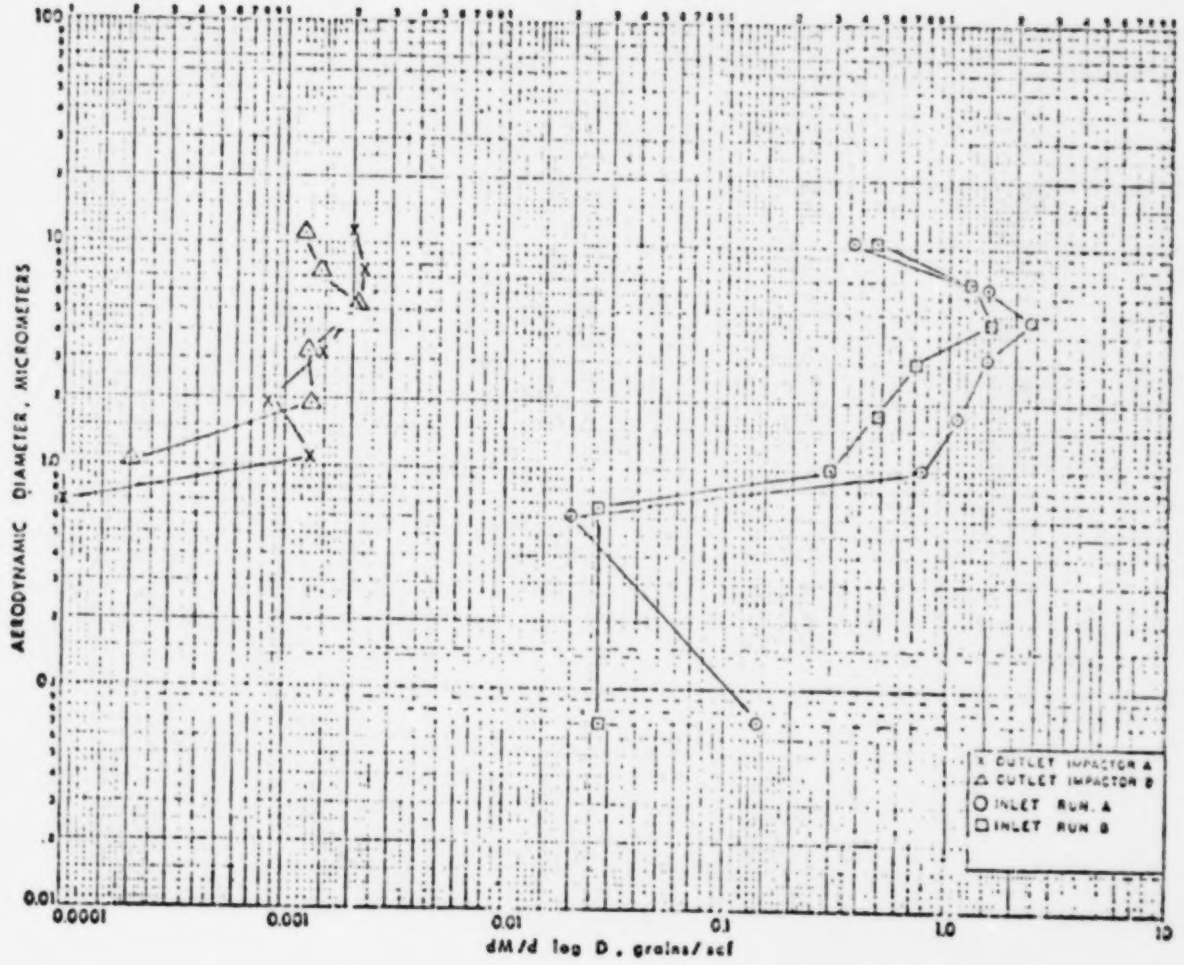


Figure 83. Differential particle size distribution for run 8

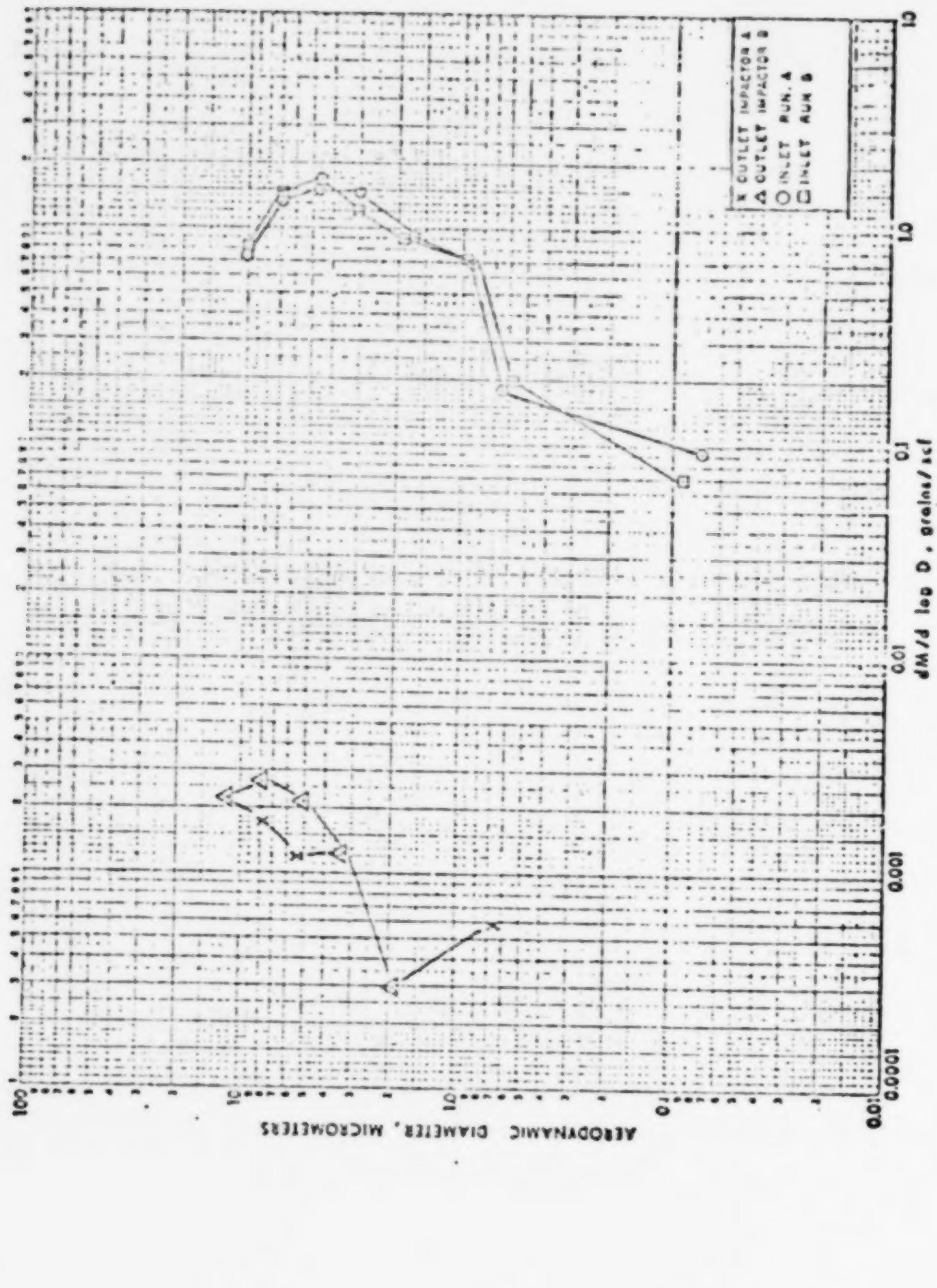


Figure 84. Differential particle size distribution for run 9

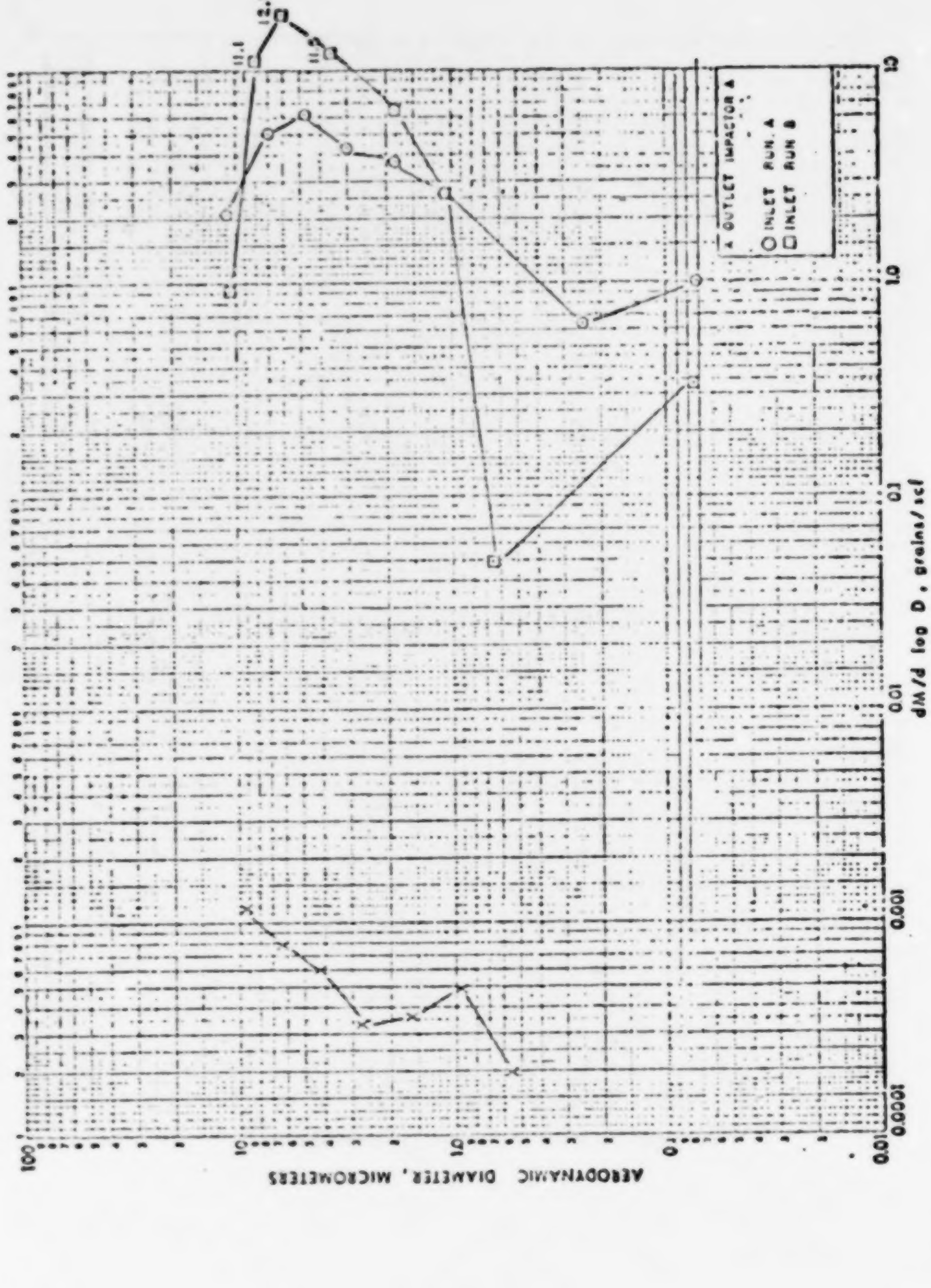


Figure 85. Differential particle size distribution for run 10

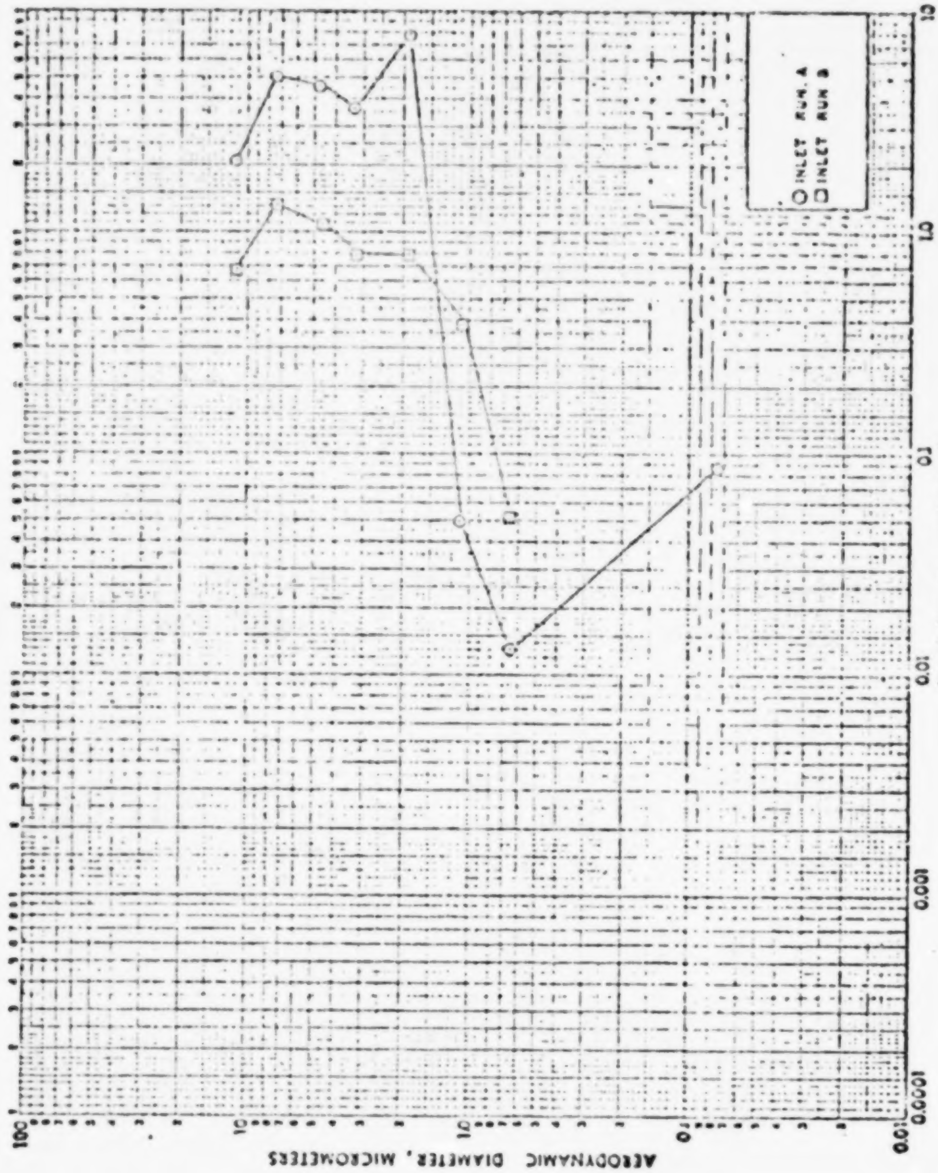


Figure 86. Differential particle size distribution for run 11

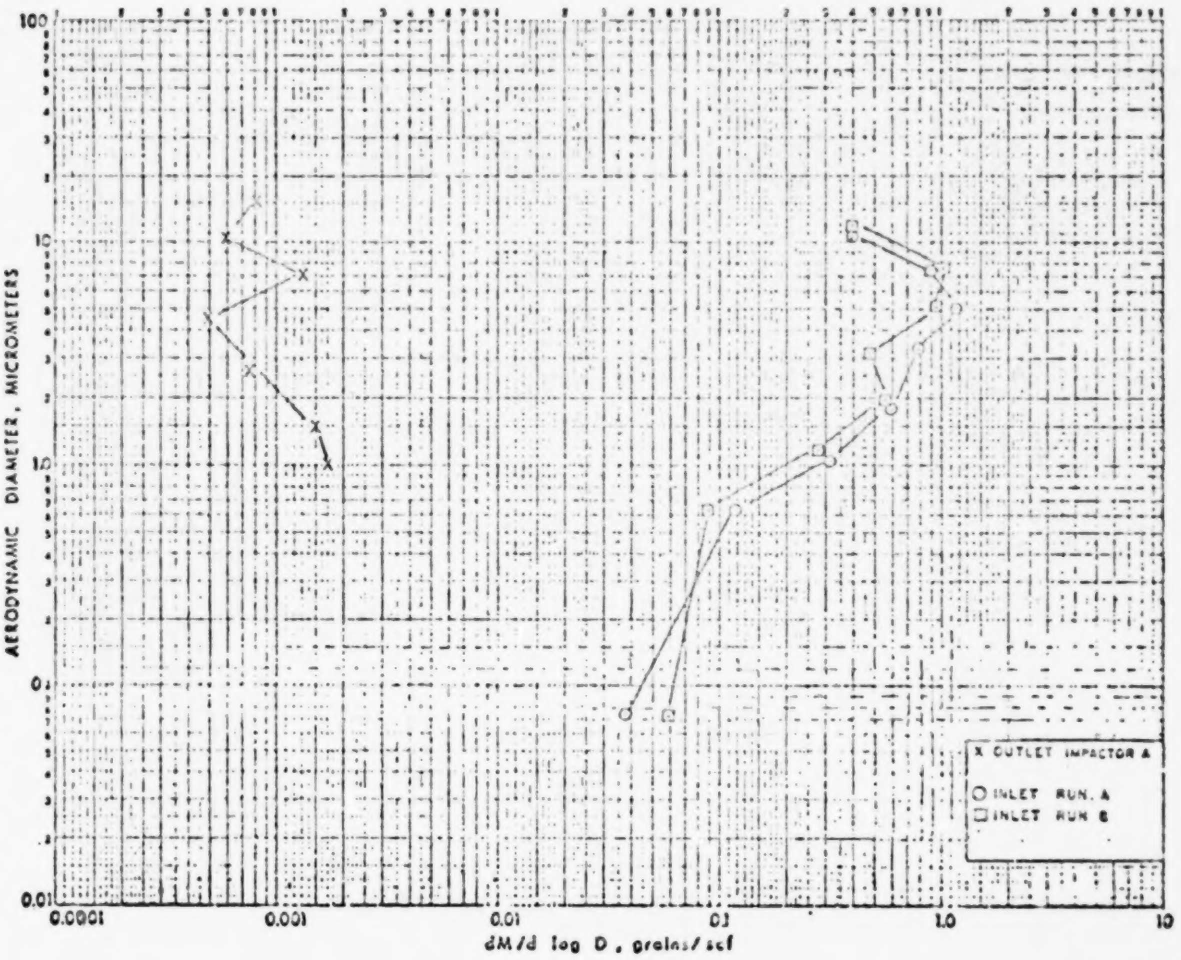


Figure 87. Differential particle size distribution for run 12

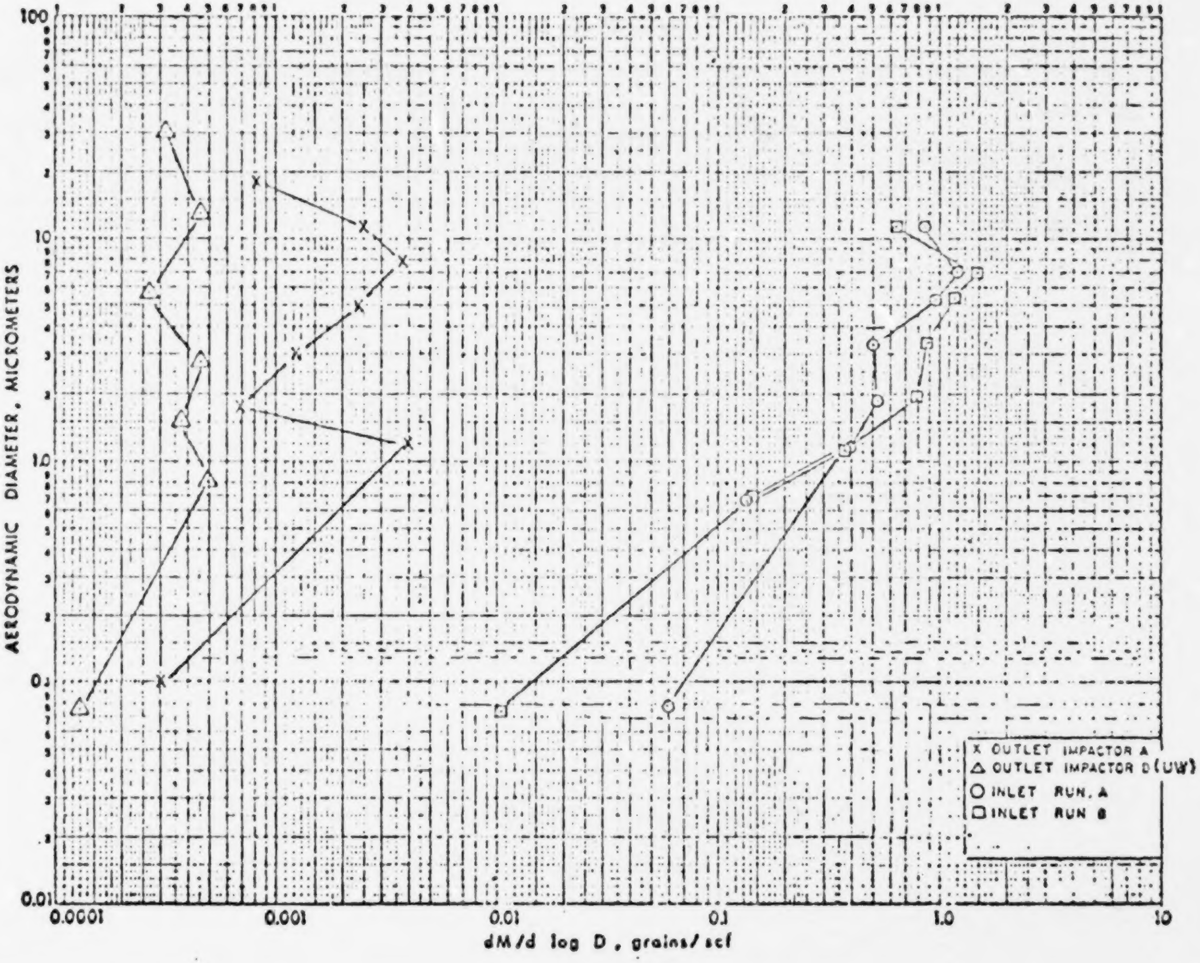


Figure 88. Differential particle size distribution for run 13

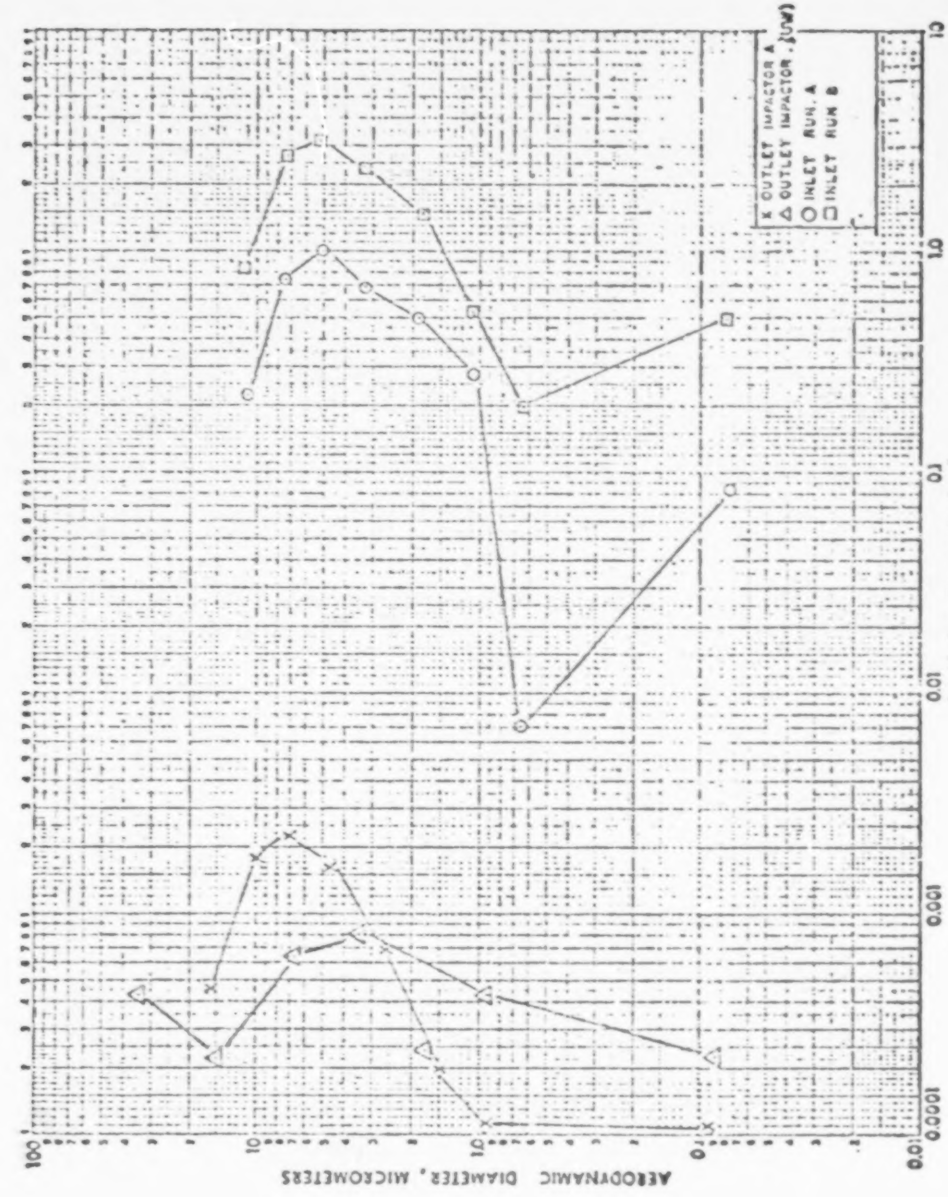


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Figure 89. Differential particle size distribution for run 14

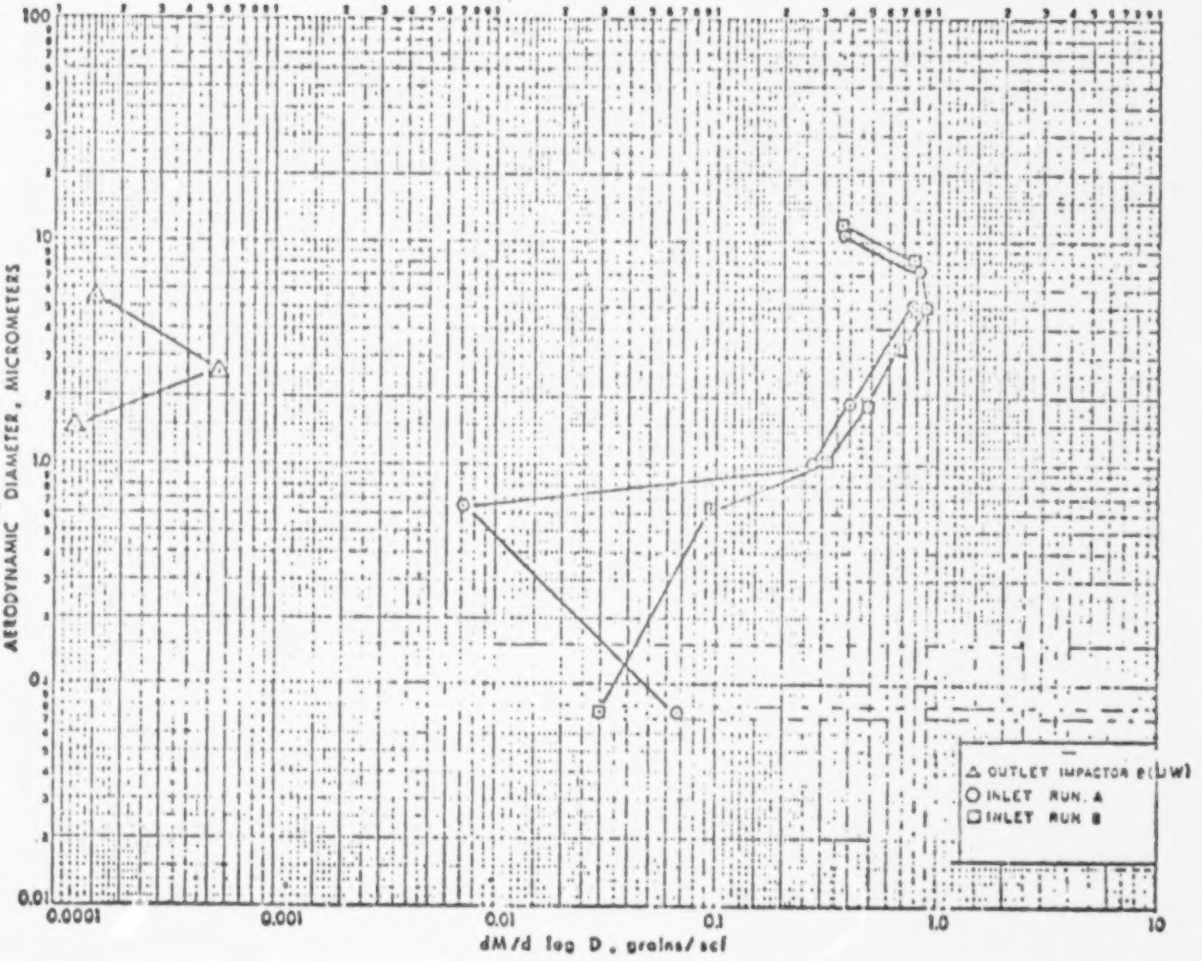

Figure 90. Differential particle size differential for run 15

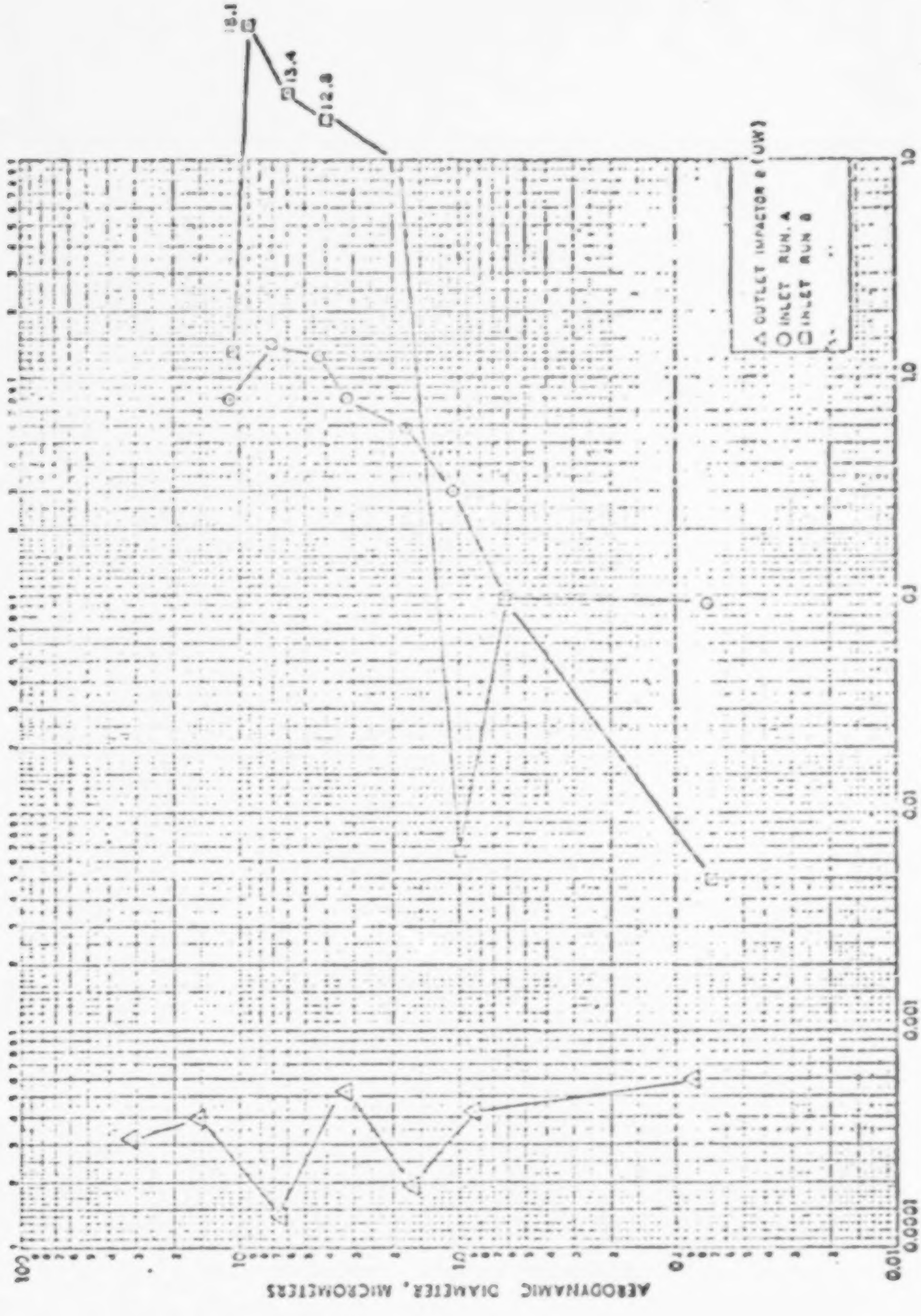

Figure 91. Differential particle size distribution for run 16

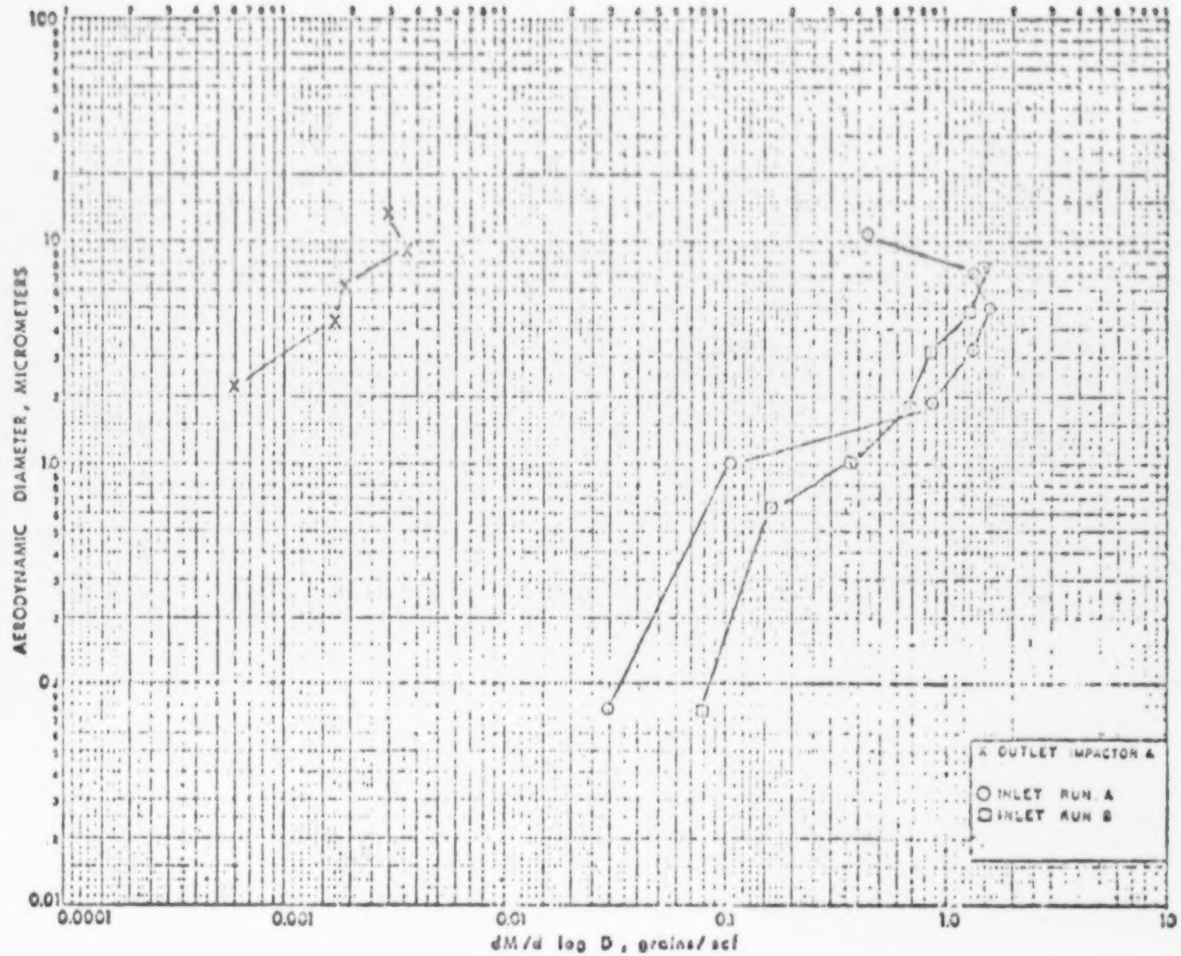

Figure 92. Differential particle size distribution for run 17

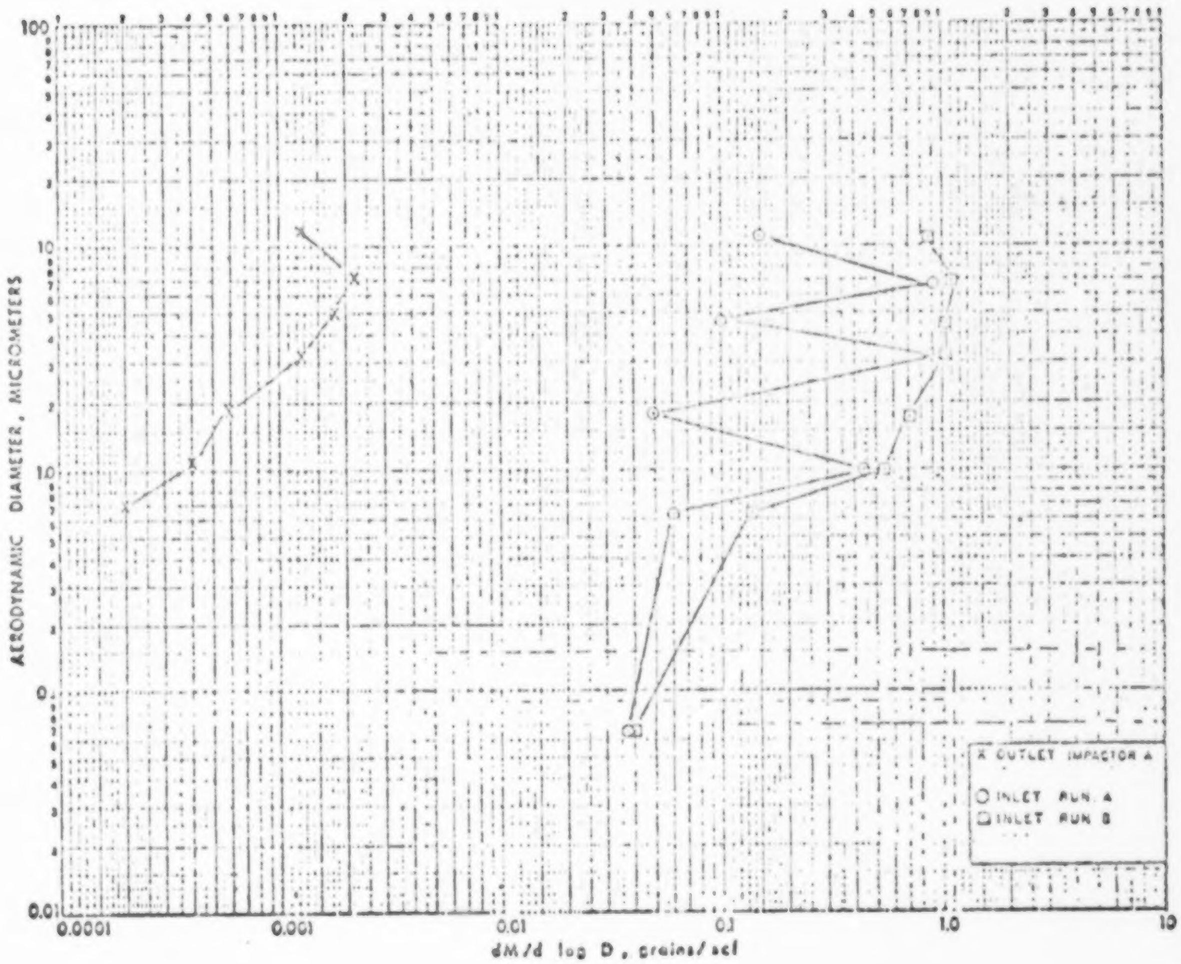

Figure 93. Differential particle size distribution for run 18

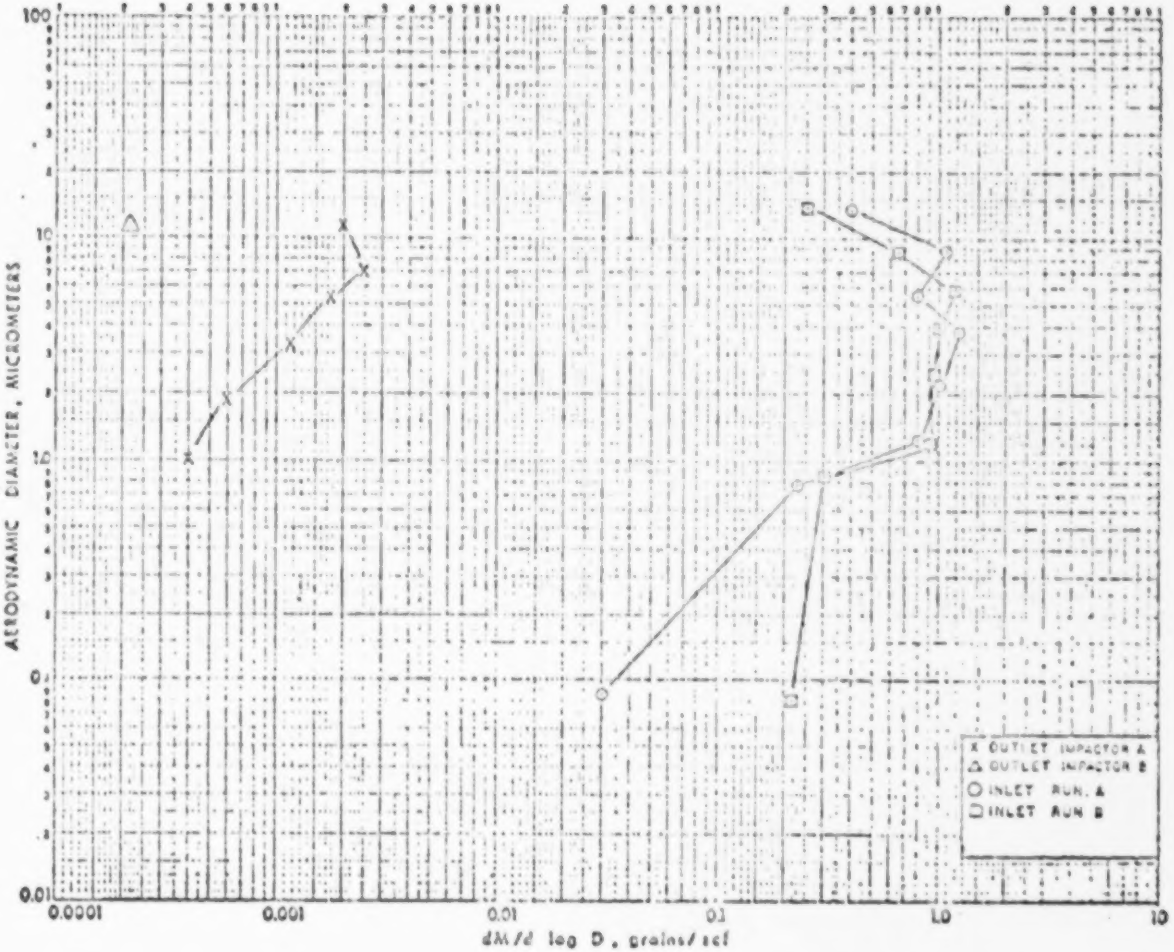

Figure 94. Differential particle size distribution for run 19

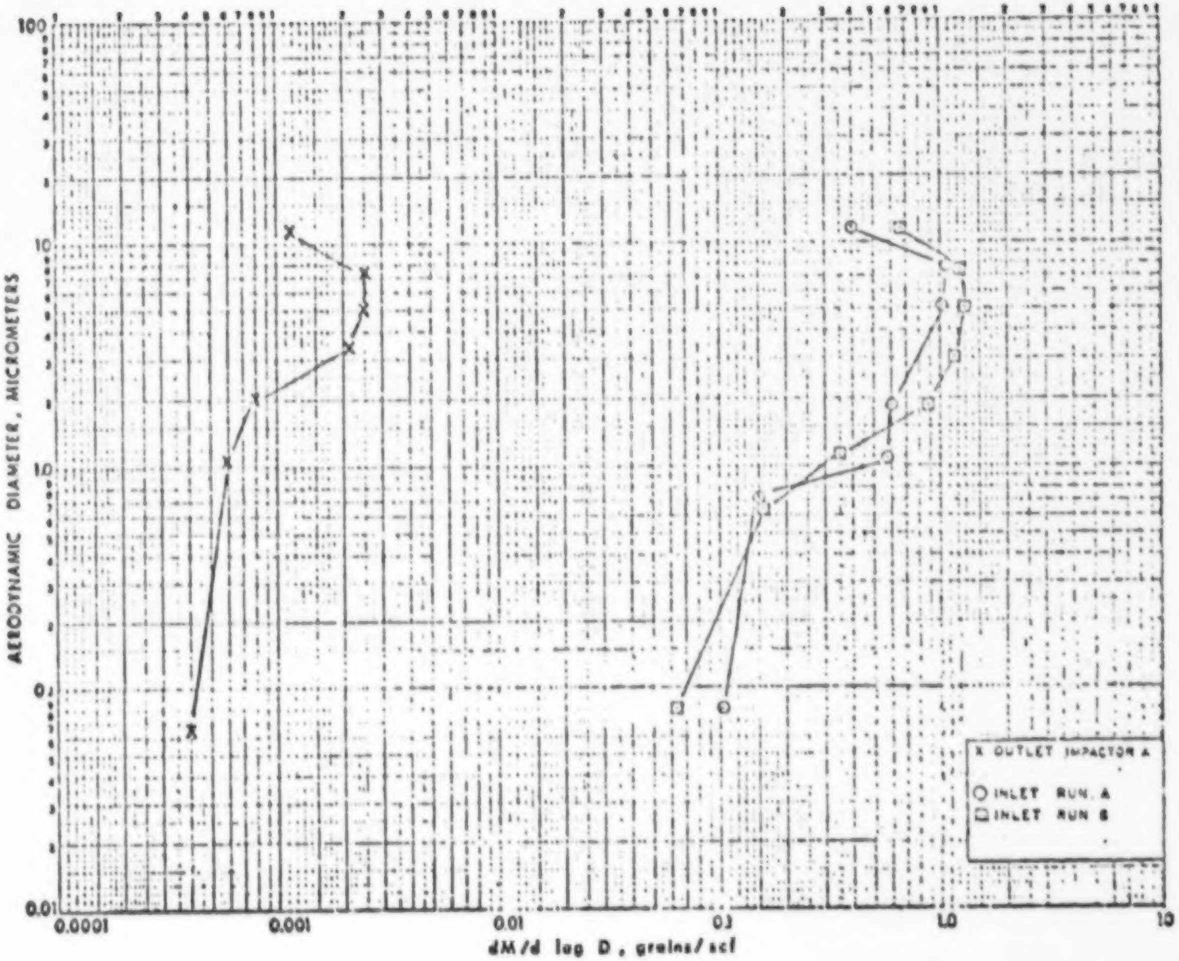

Figure 95. Differential particle size distribution for run 20

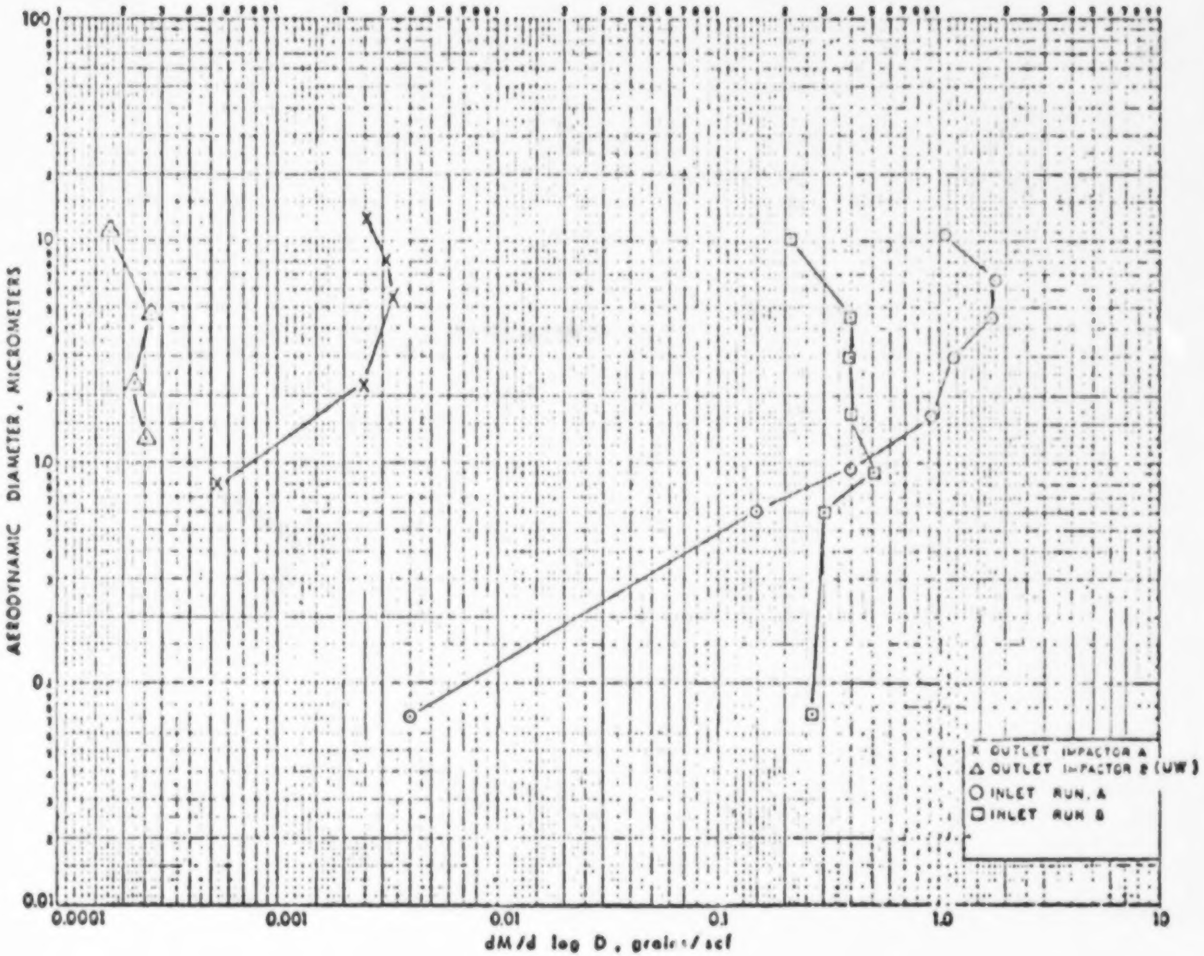

Figure 96. Differential particle size distribution for run 21

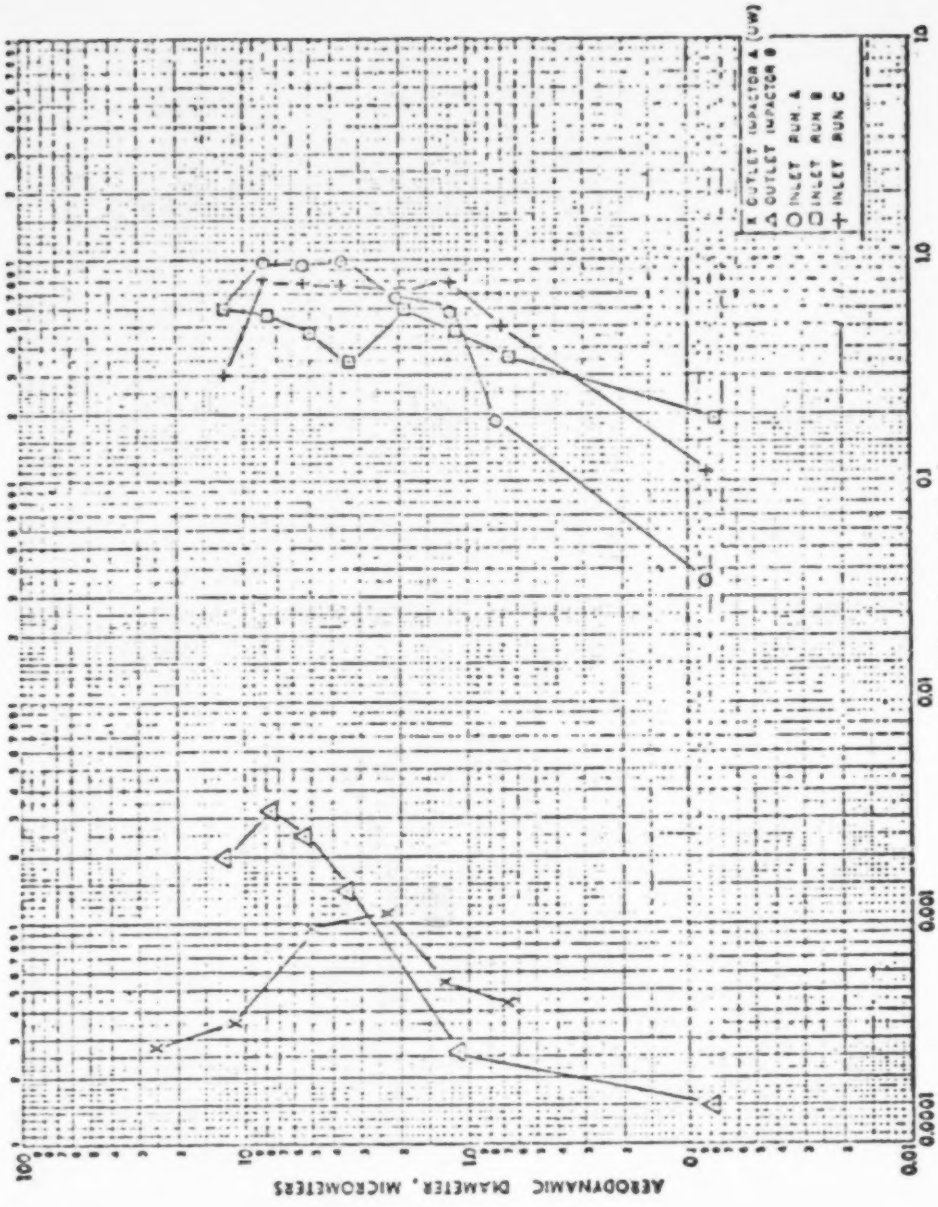

Figure 97. Differential particle size distribution for run 22

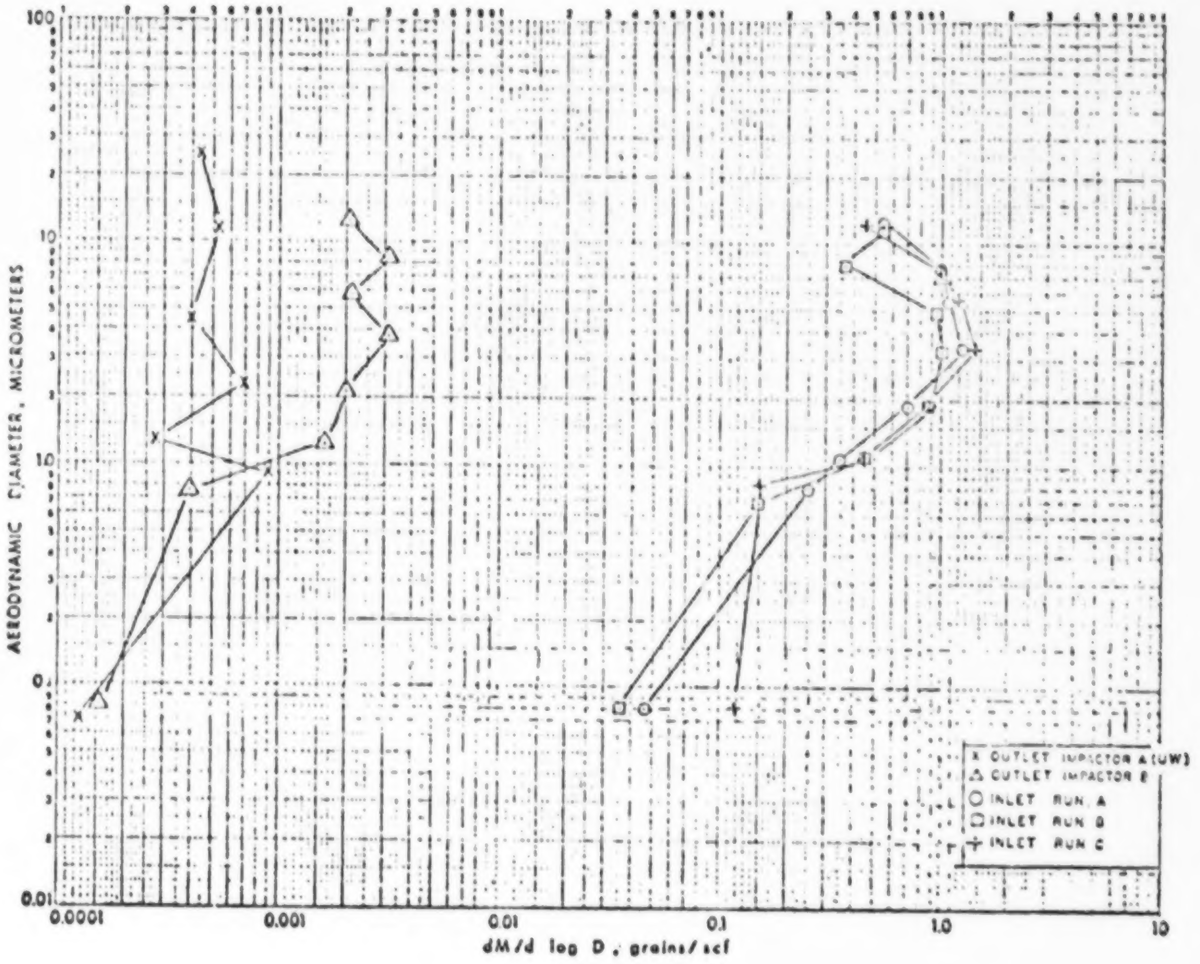

Figure 98. Differential particle size distribution for run 23

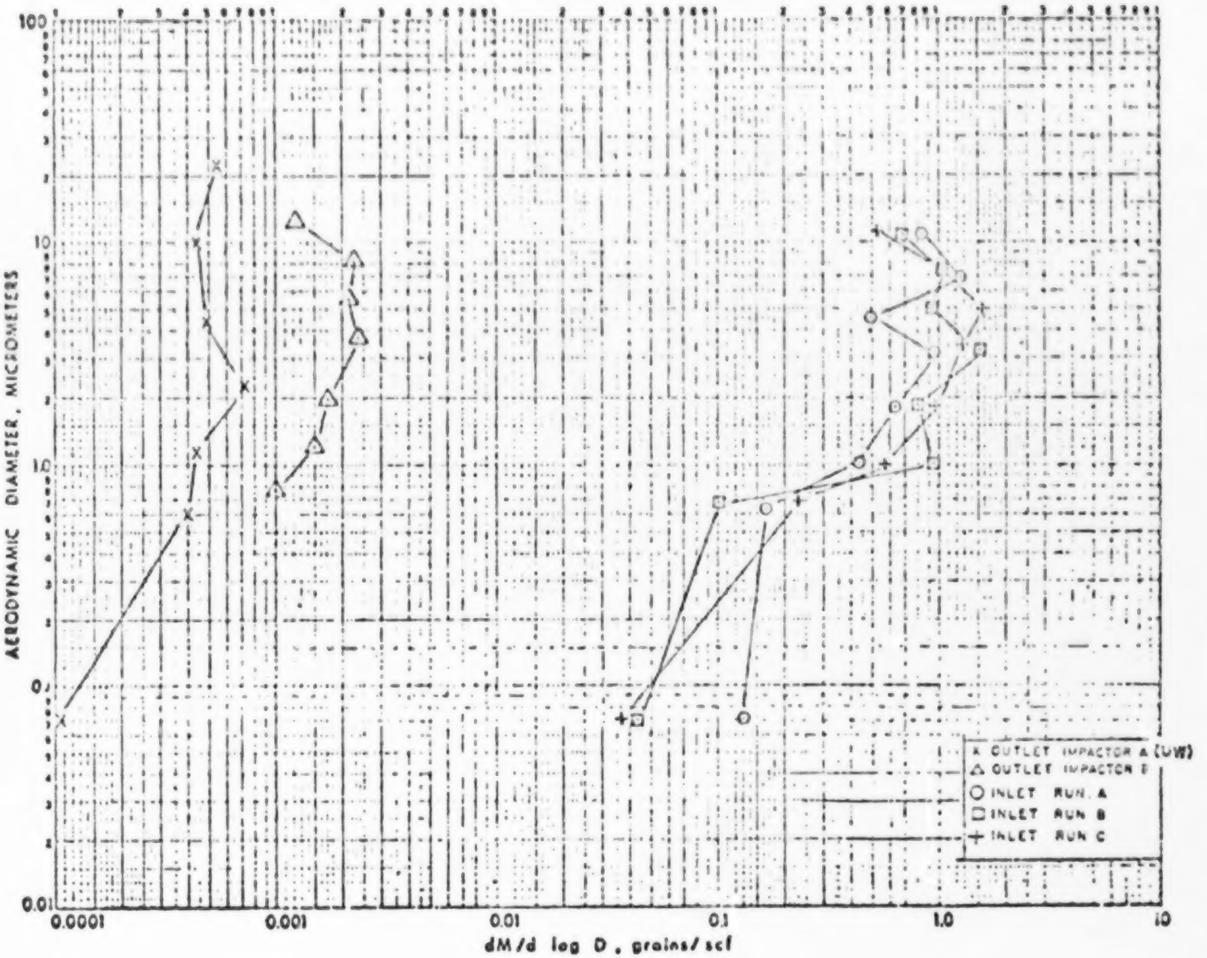

Figure 99. Differential particle size distribution for run 24

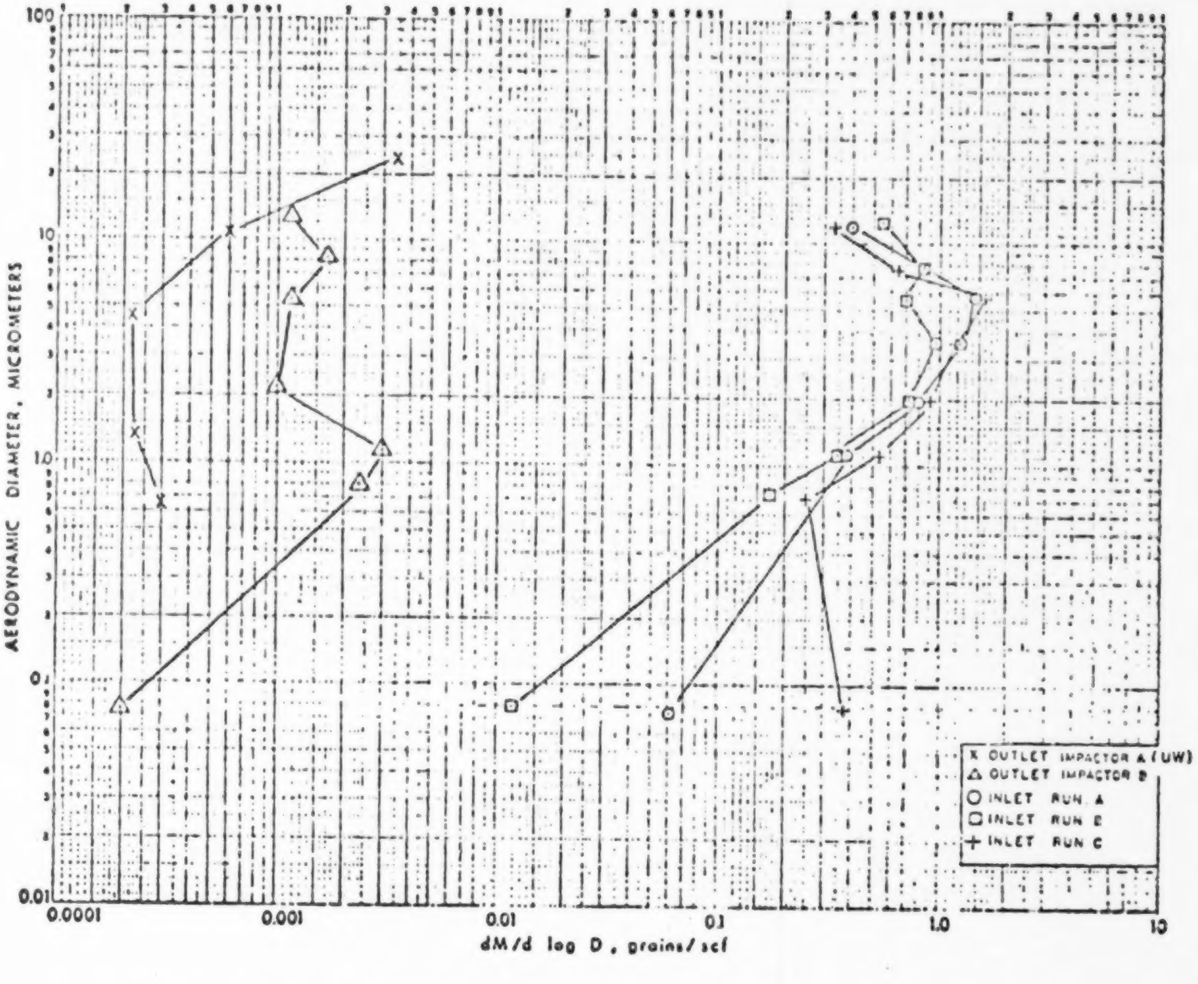

Figure 100. Differential particle size distribution for run 25

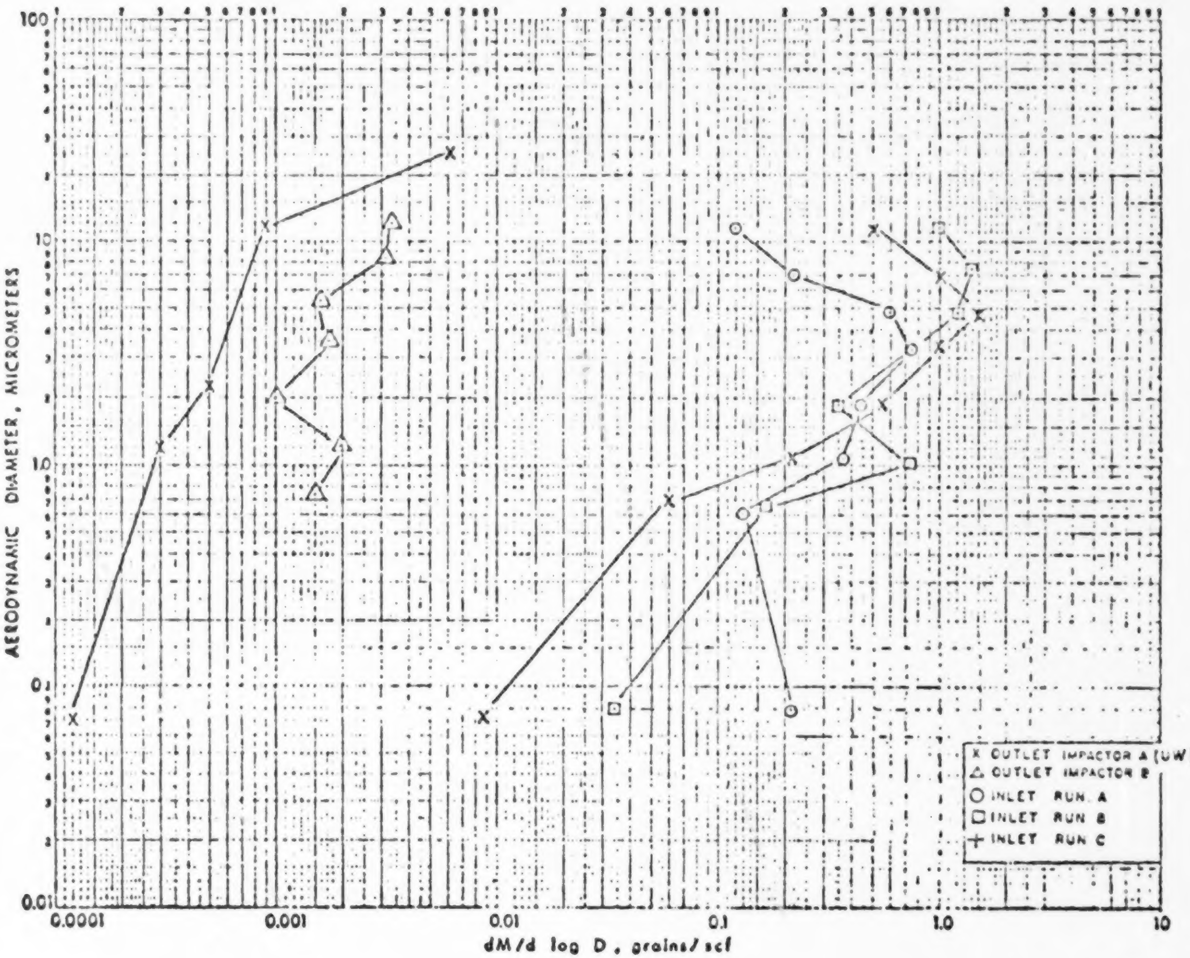

Figure 101. Differential particle size distribution for run 26

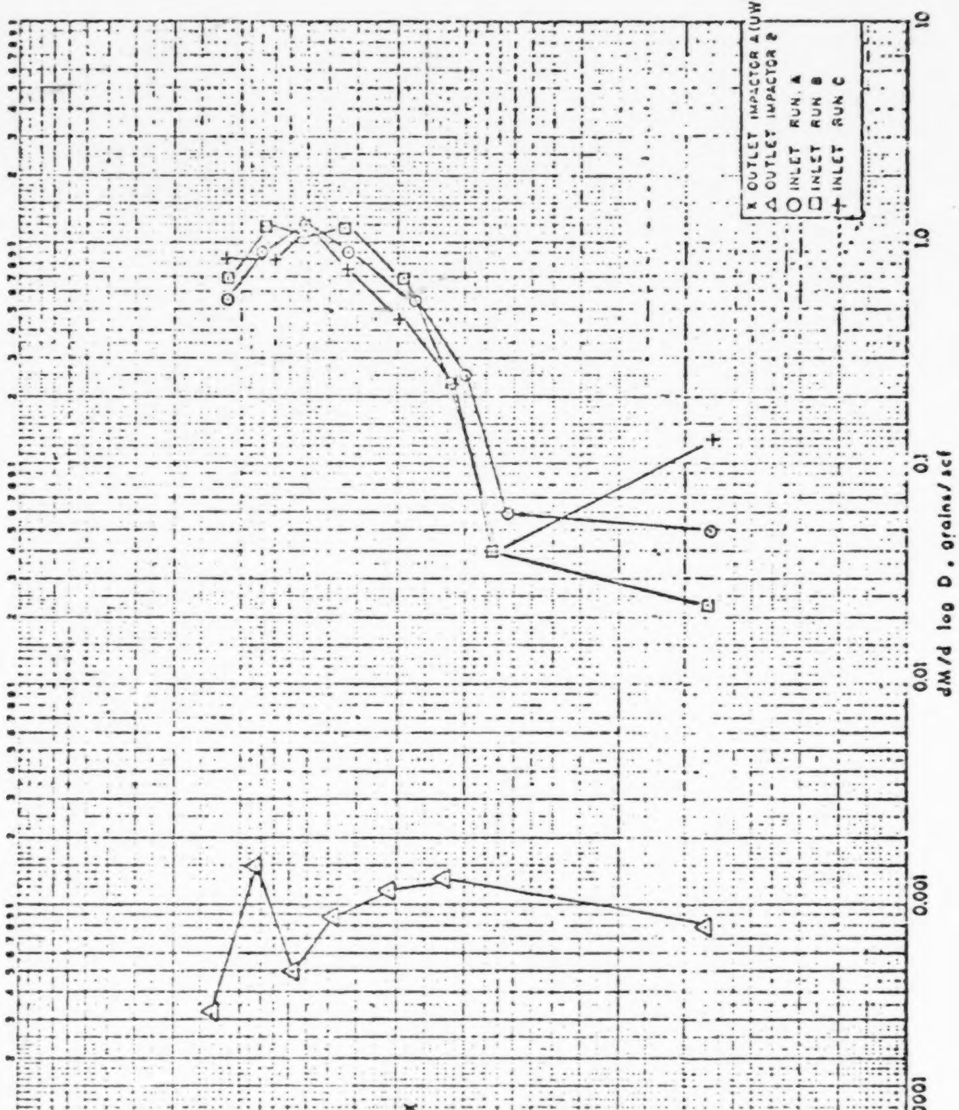

Figure 102. Differential particle size distribution for run 27

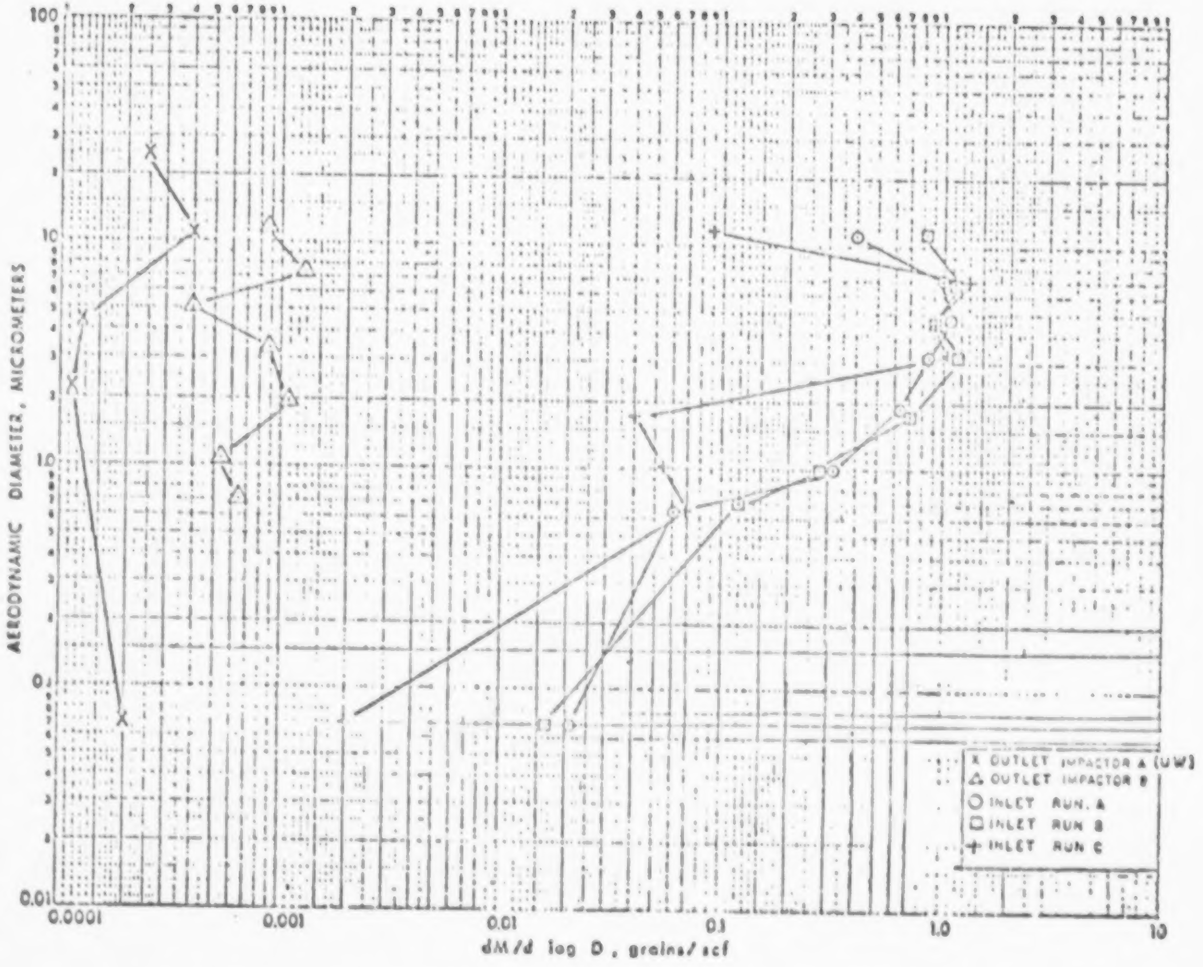

Figure 103. Differential particle size distribution for run 28

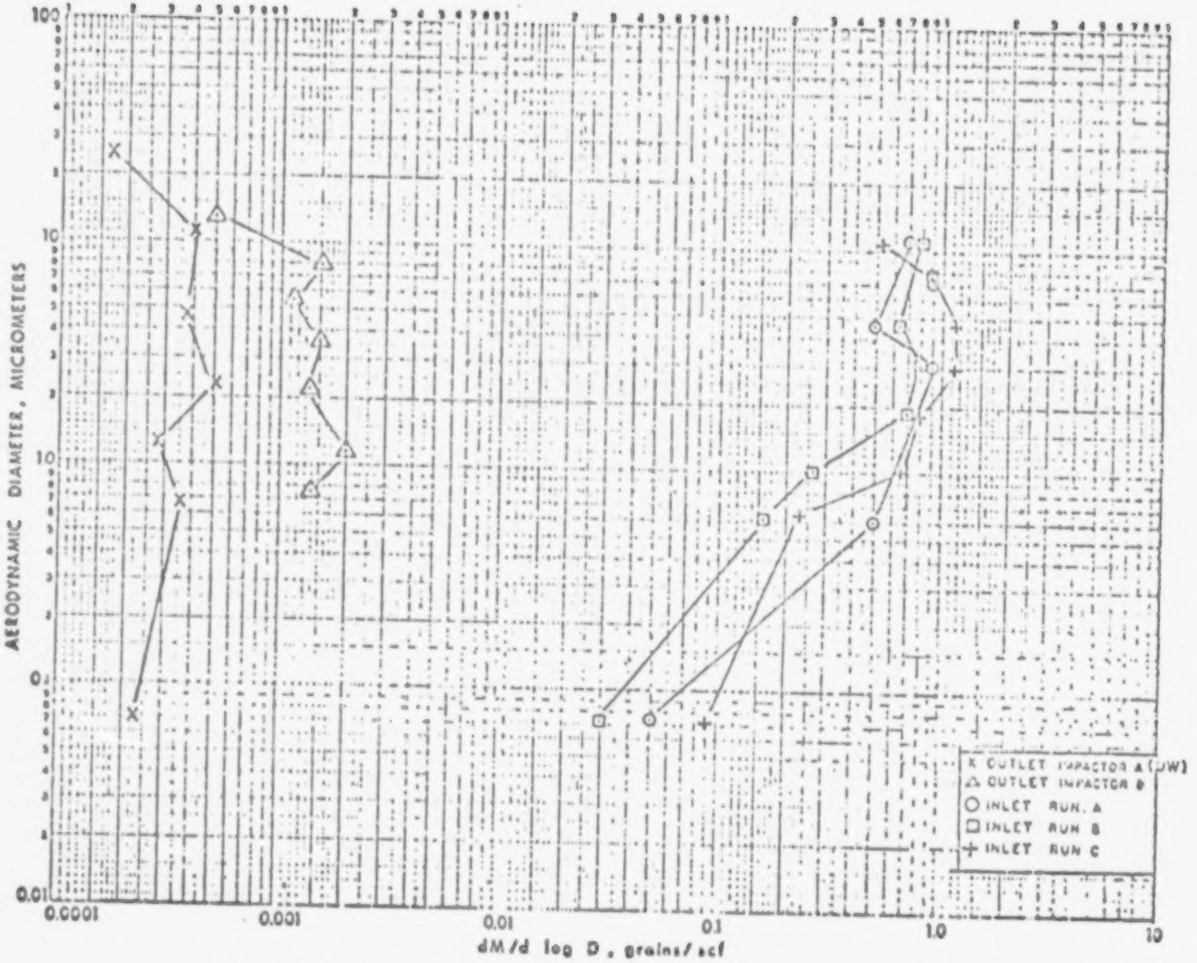

Figure 104. Differential particle size distribution for run 29

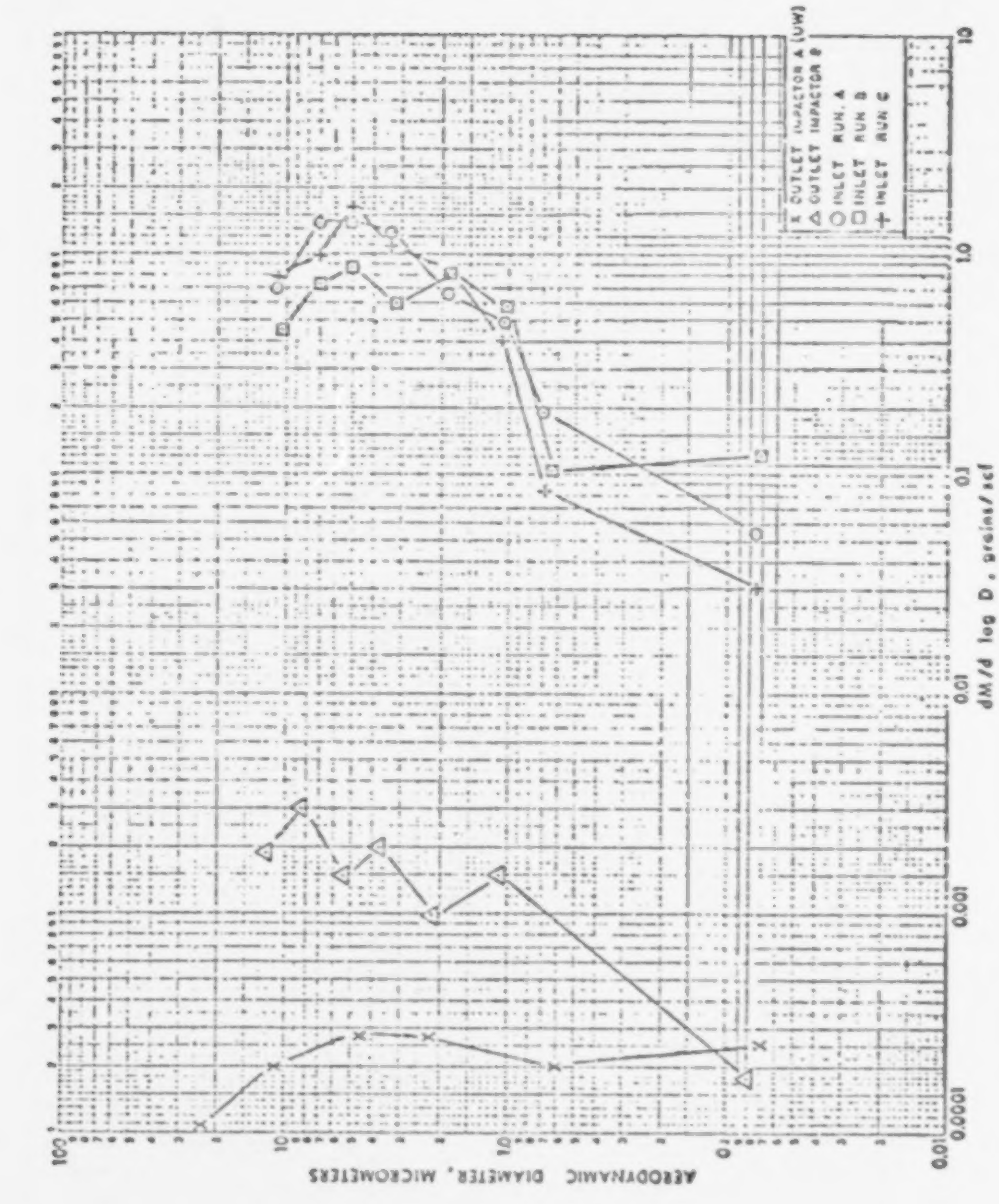

Figure 105. Differential particle size distribution for run 30

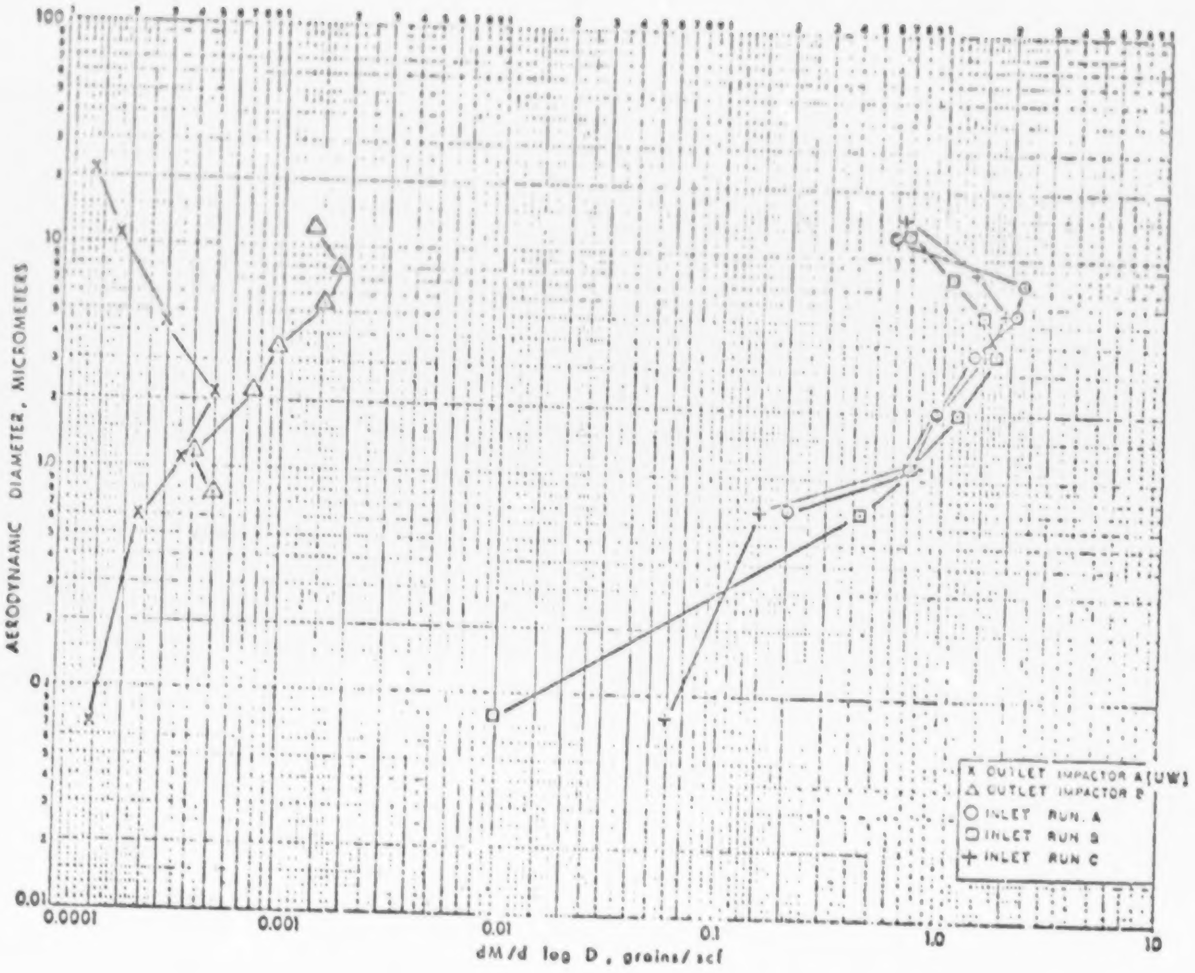

Figure 106. Differential particle size distribution for run 31

APPENDIX C

FRACTIONAL EFFICIENCY/PENETRATION CURVES

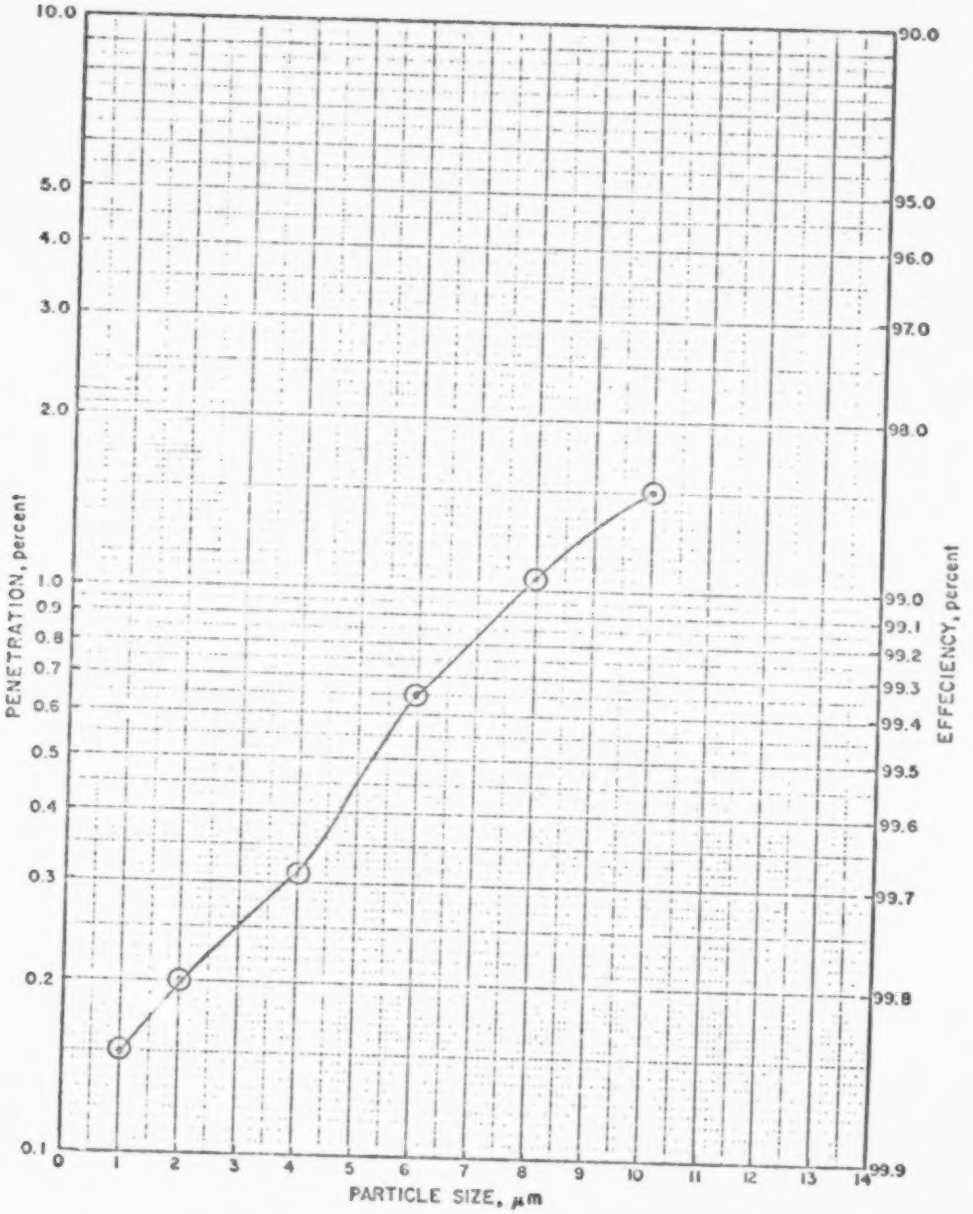

Figure 107. Penetration/efficiency as a function of size for run 1

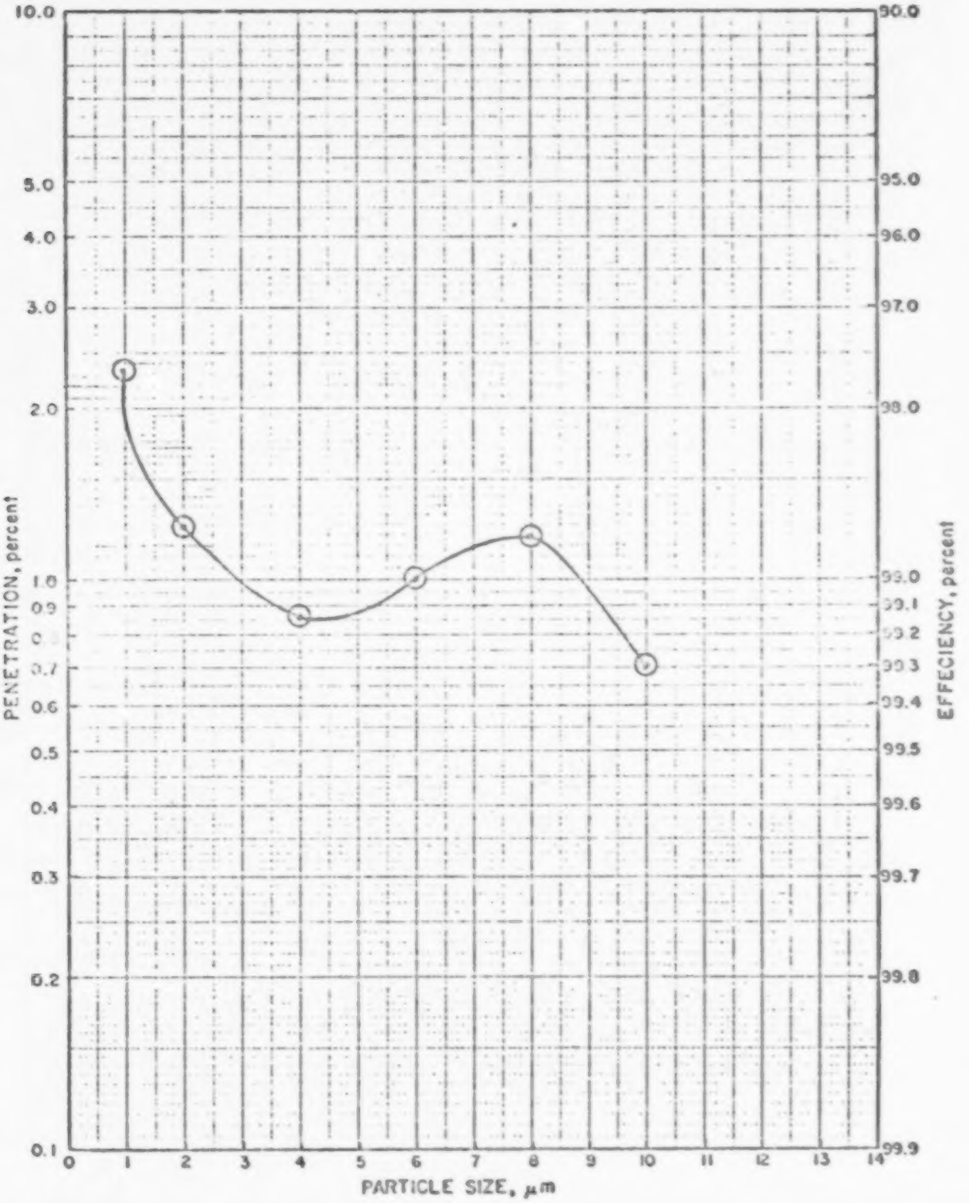

Figure 108. Penetration/efficiency as a function of size for run 2

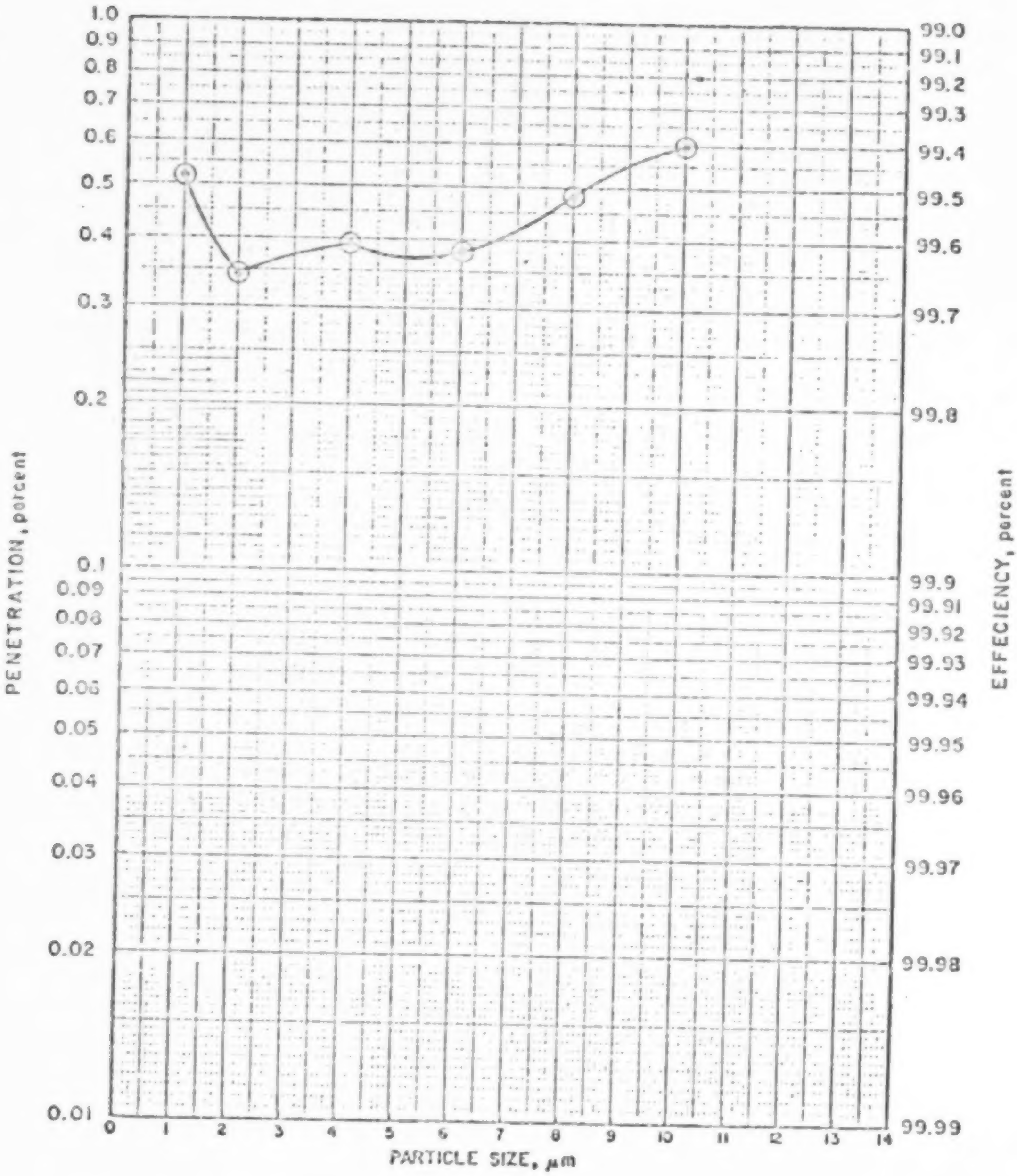

Figure 109. Penetration/efficiency as a function of size for run 3

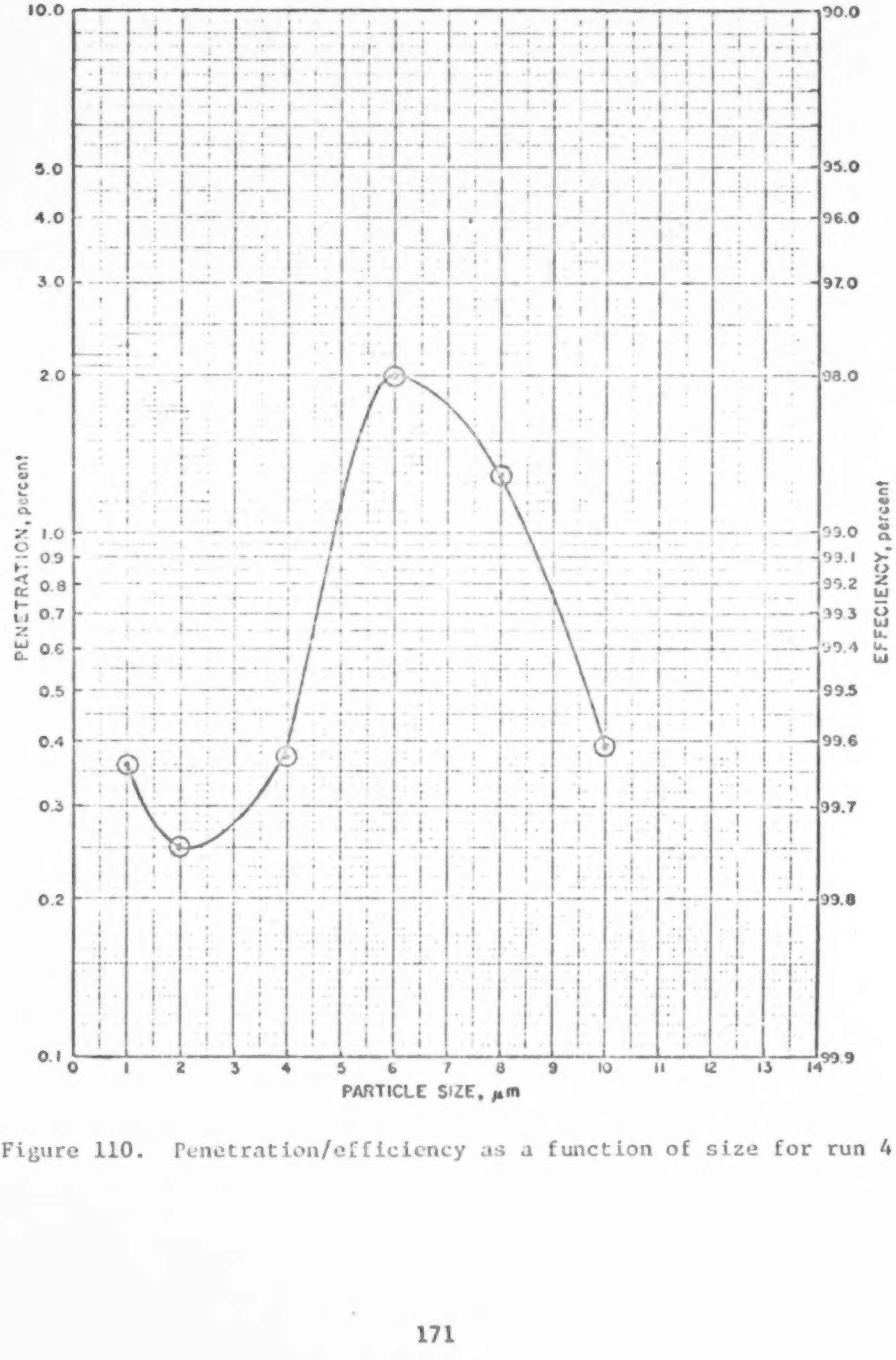

Figure 110. Penetration/efficiency as a function of size for run 4

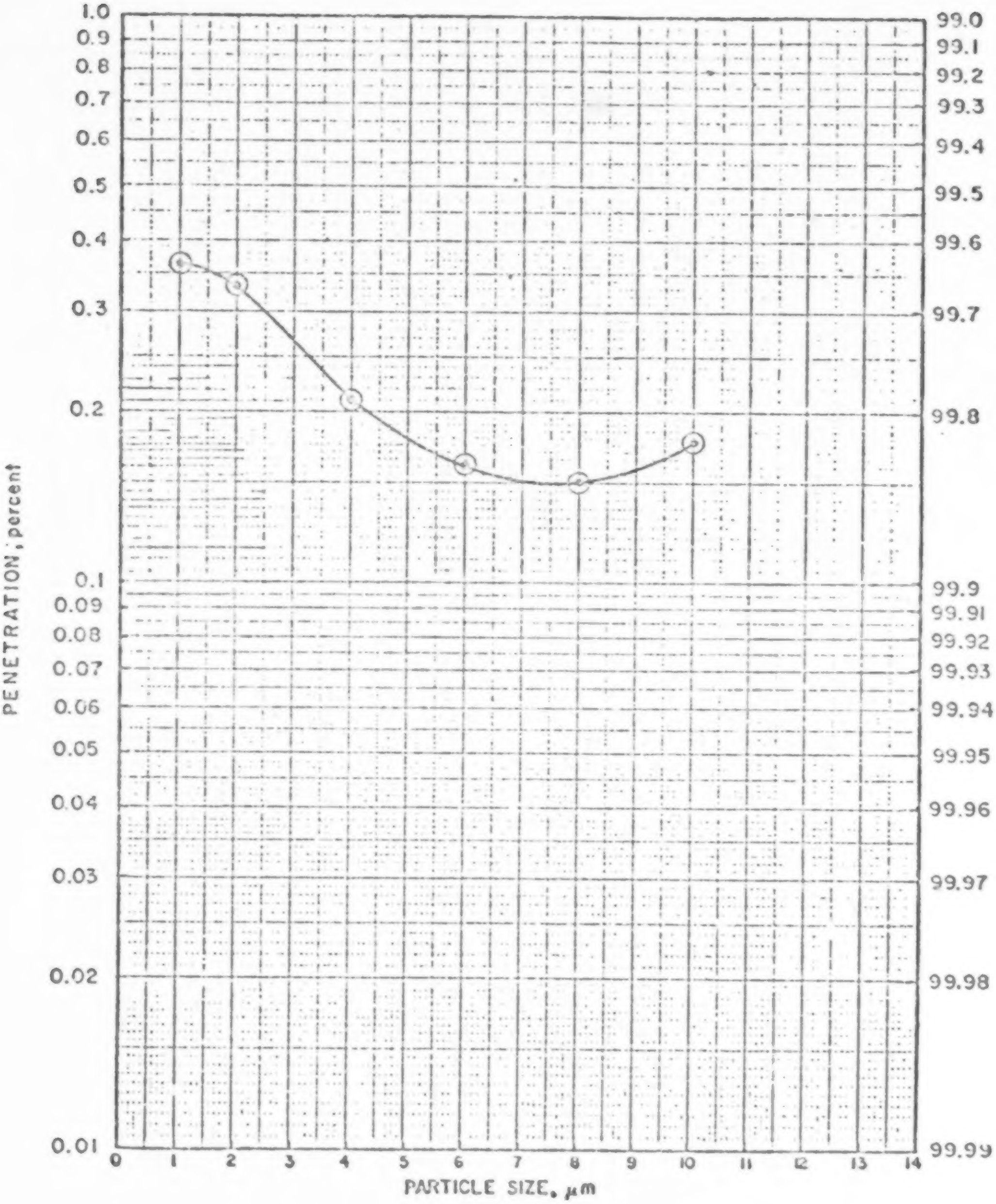

Figure 111. Penetration/efficiency as a function of size for run 5

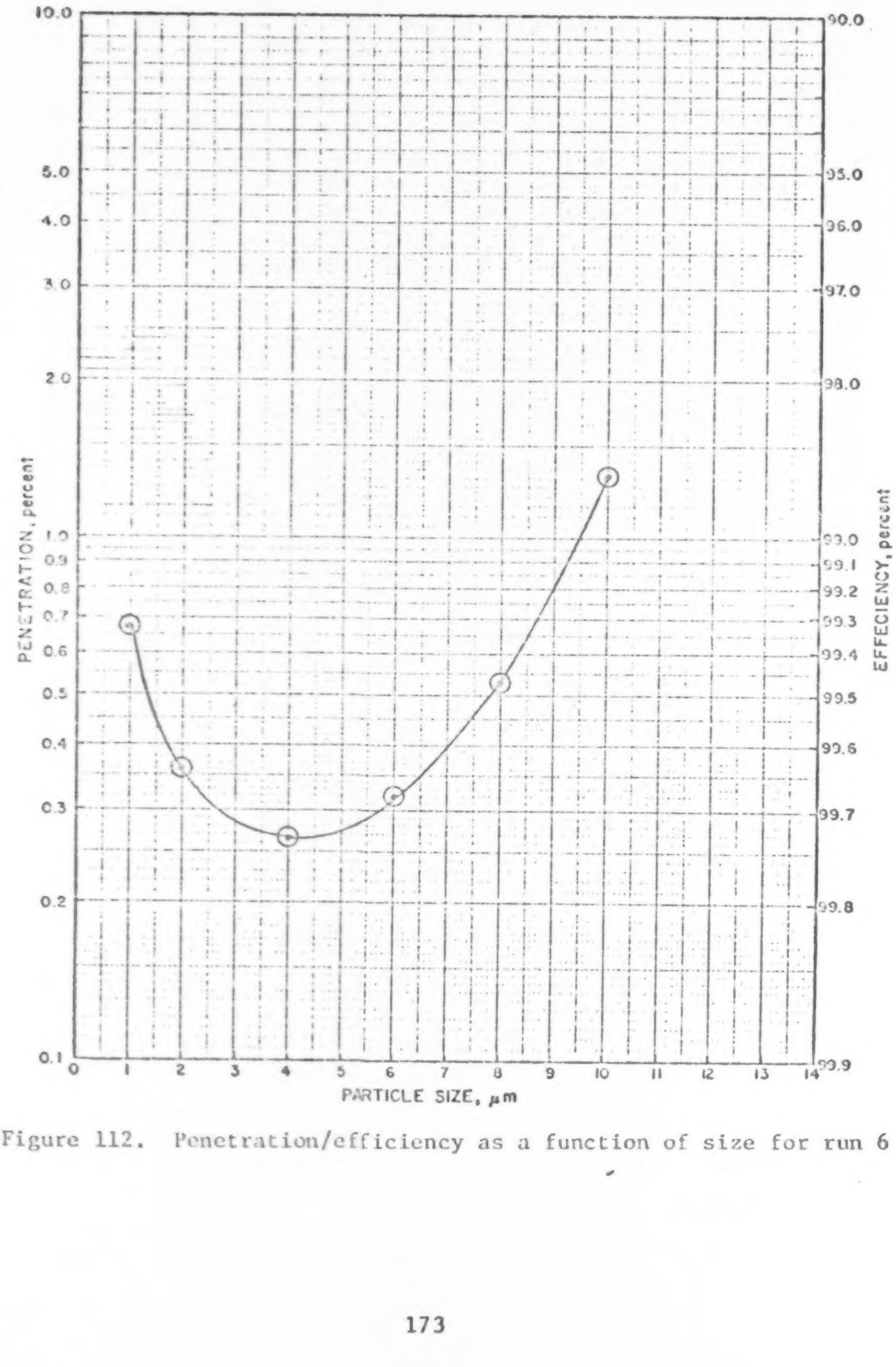

Figure 112. Penetration/efficiency as a function of size for run 6

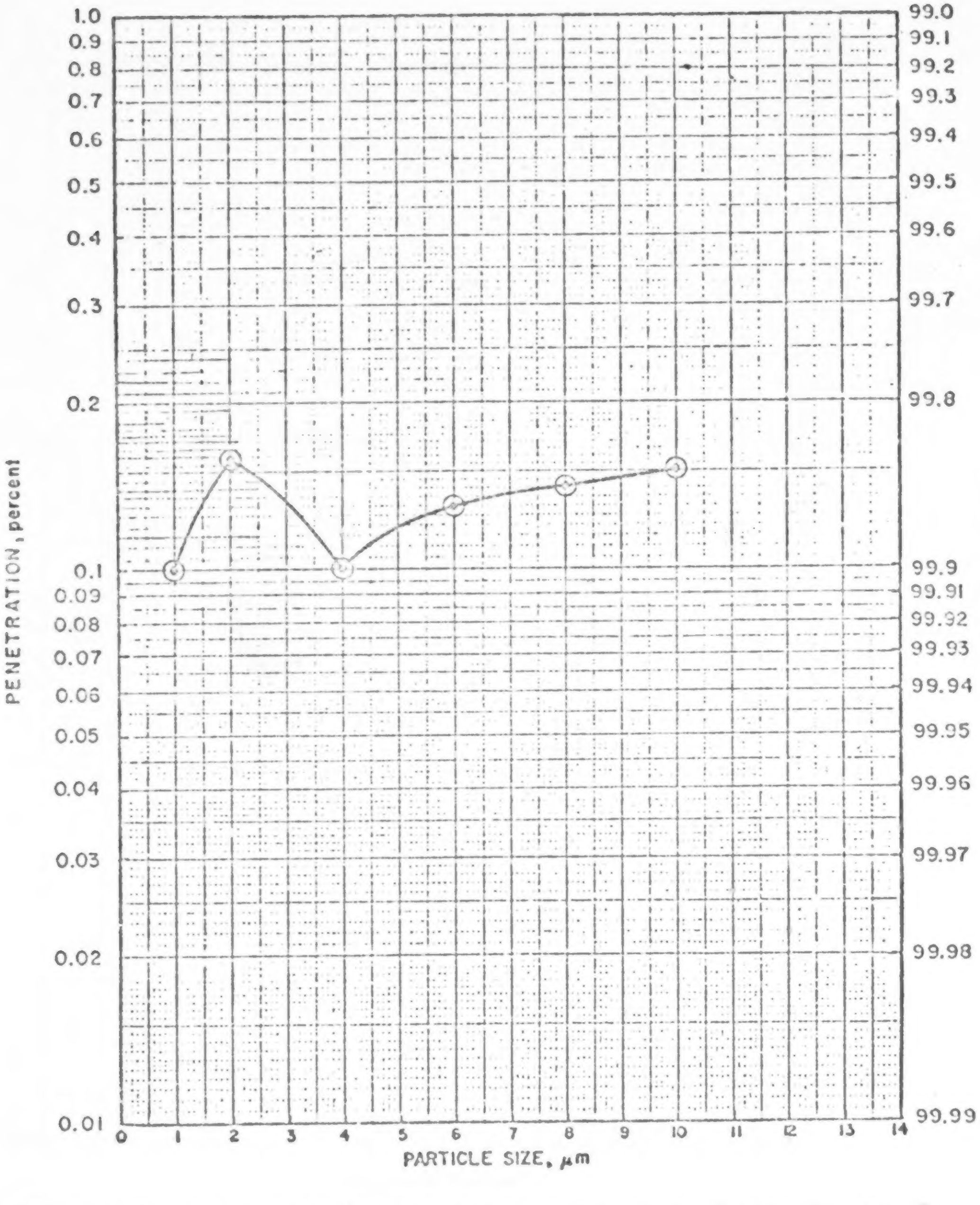

Figure 113. Penetration/efficiency as a function of size for run 7

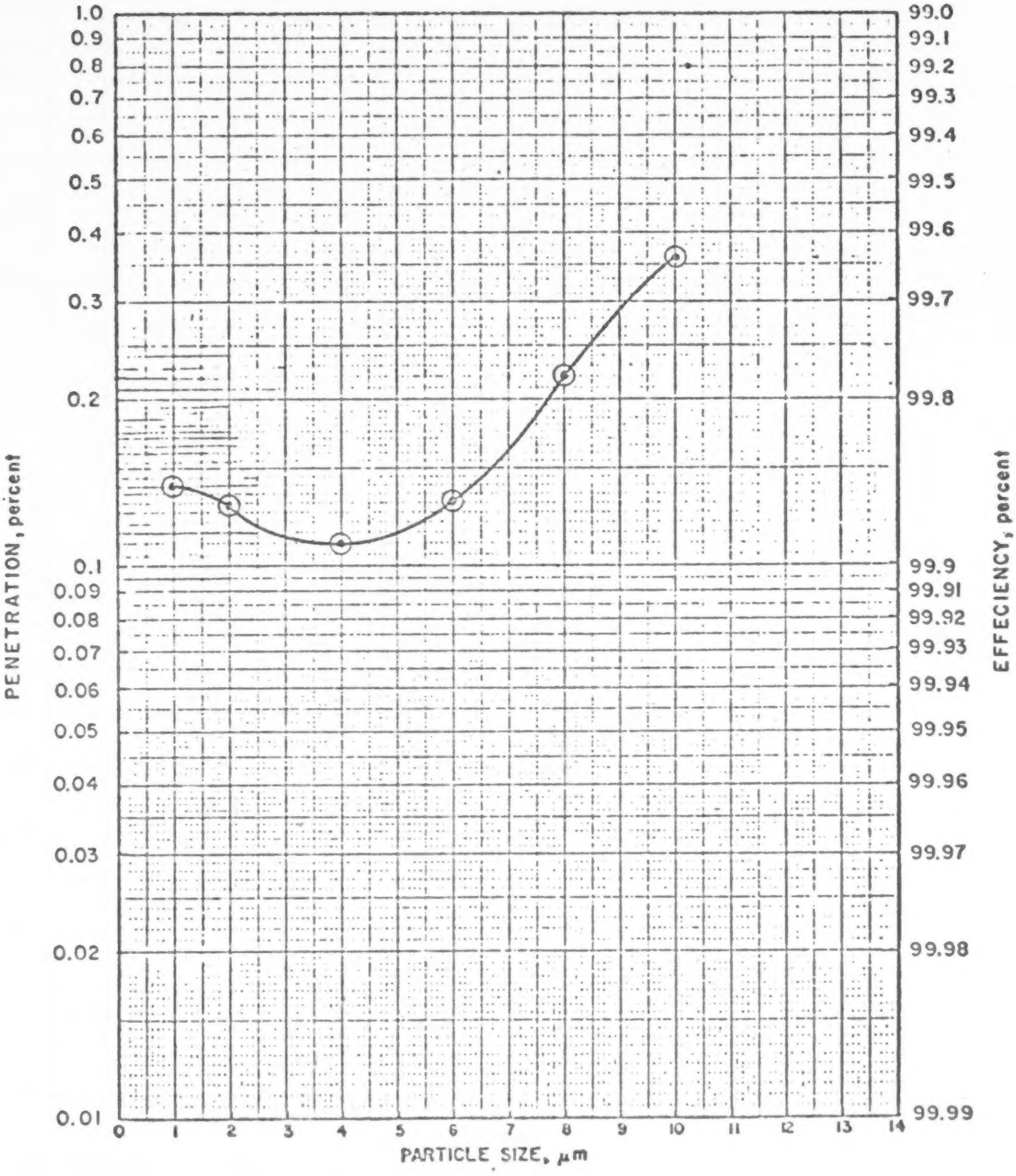

Figure 114. Penetration/efficiency as a function of size for run 8

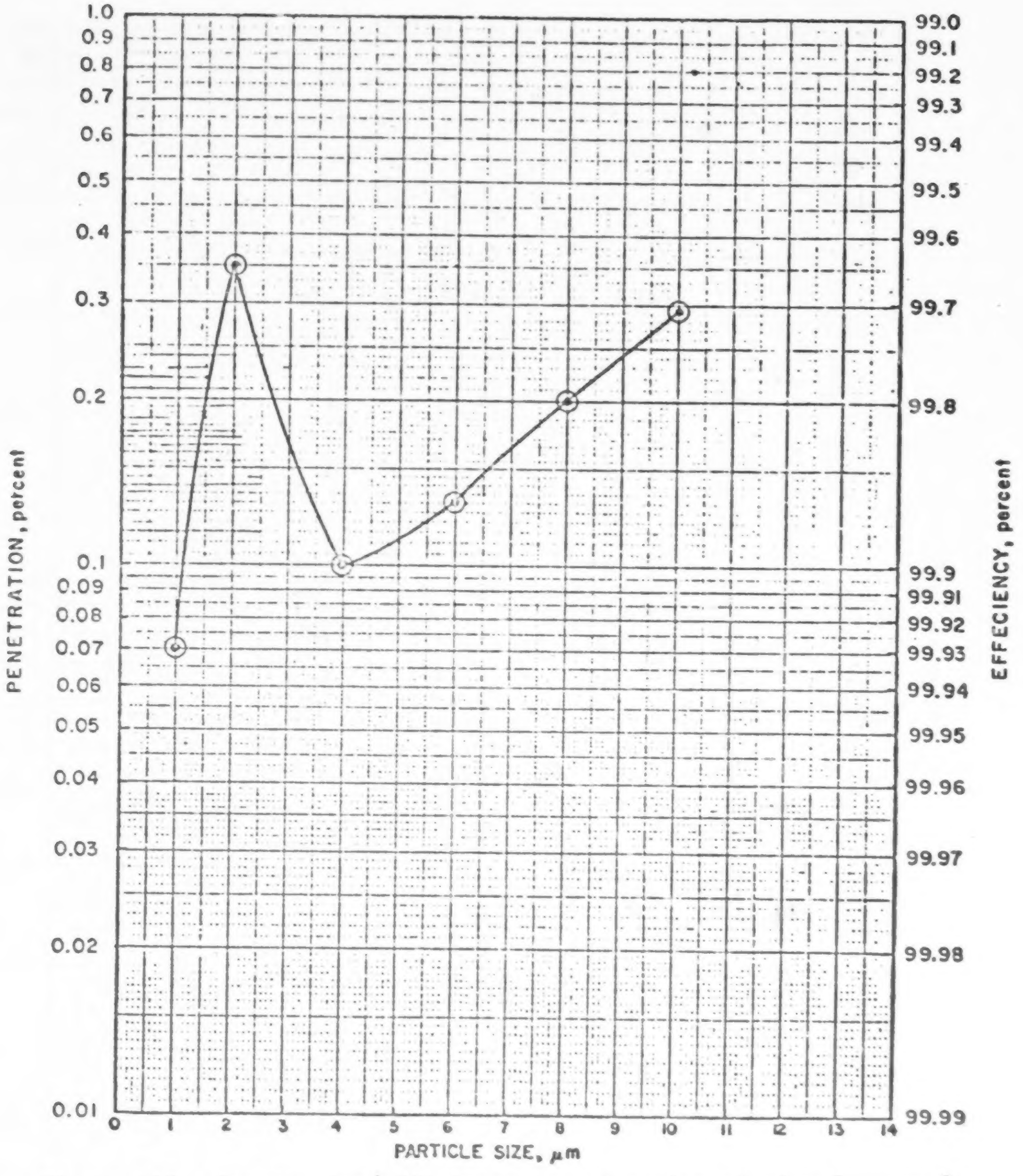

Figure 115. Penetration/efficiency as a function of size for run 9

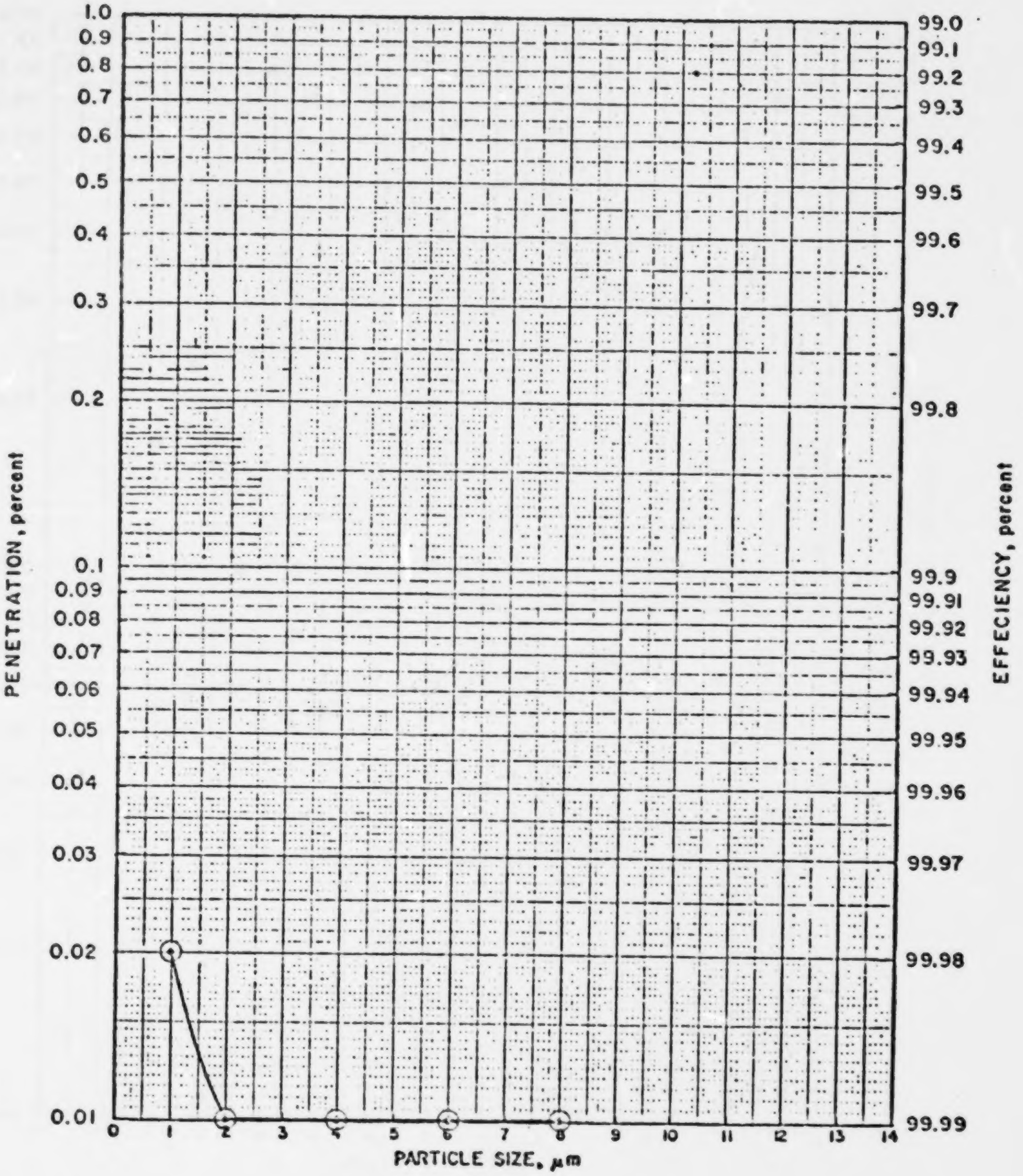

Figure 116. Penetration/efficiency as a function of size for run 10

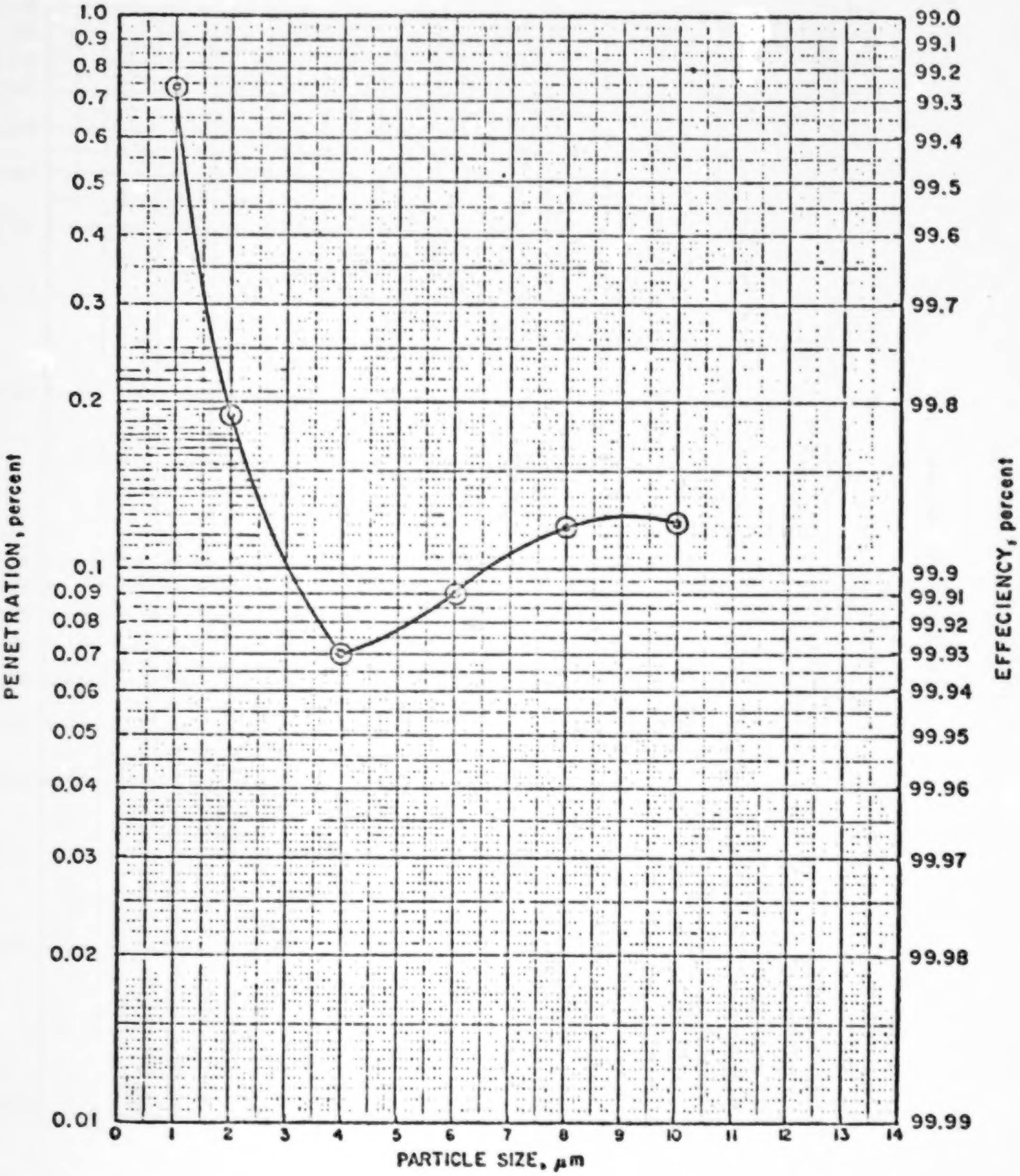

Figure 117. Penetration/efficiency as a function of size for run 12

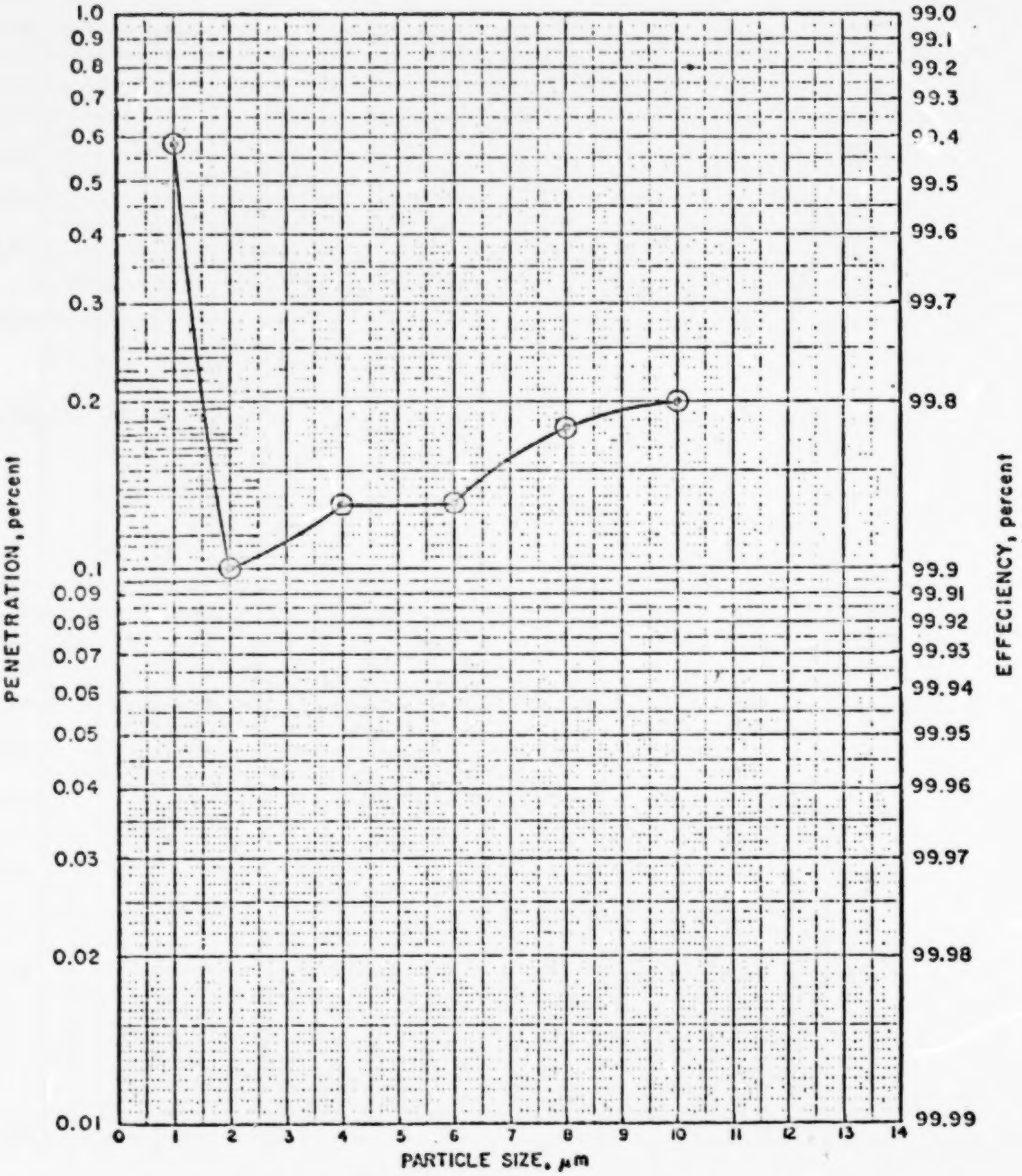

Figure 118. Penetration/efficiency as a function of size for run 13

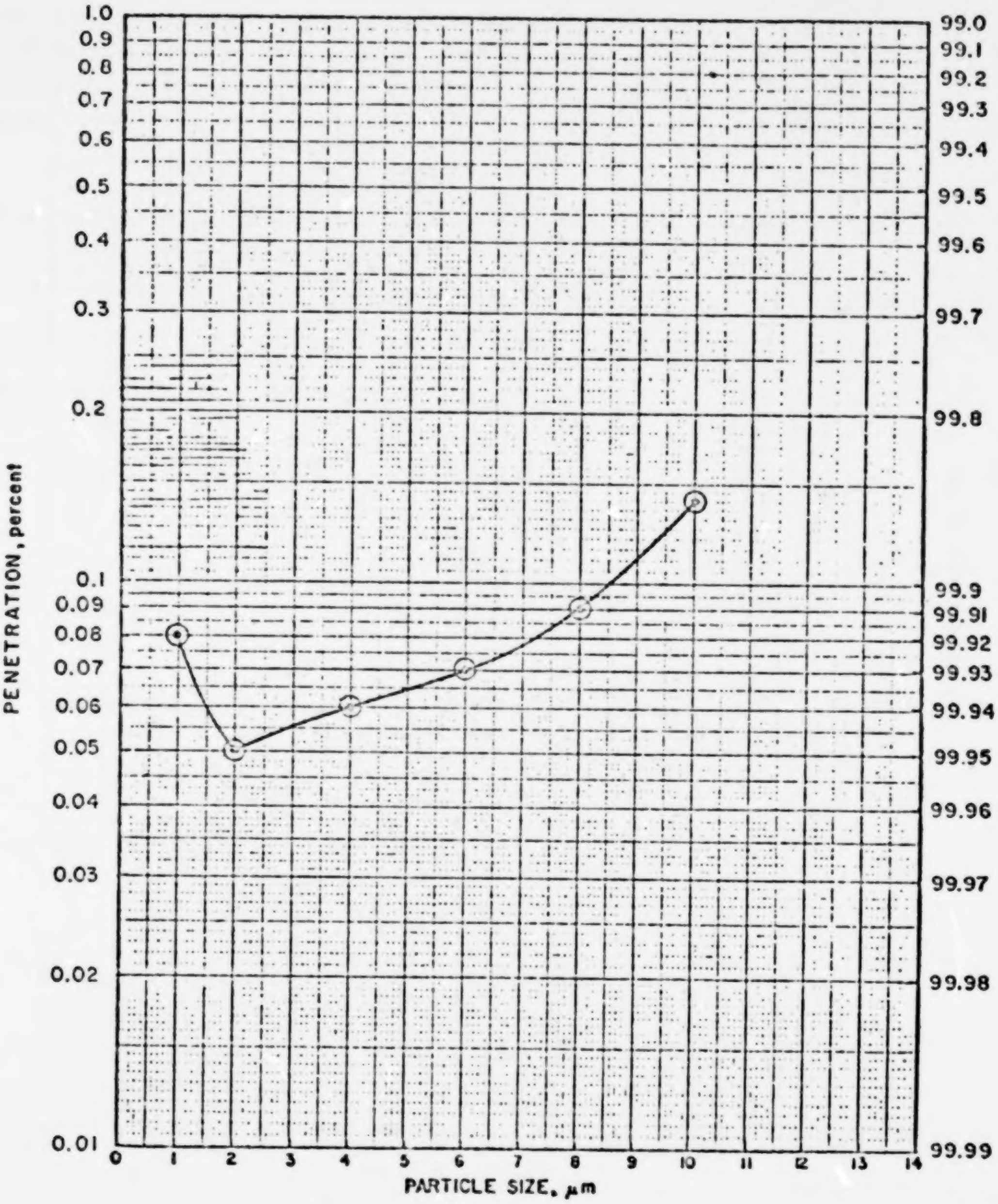

Figure 119. Penetration/efficiency as a function of size for run 14

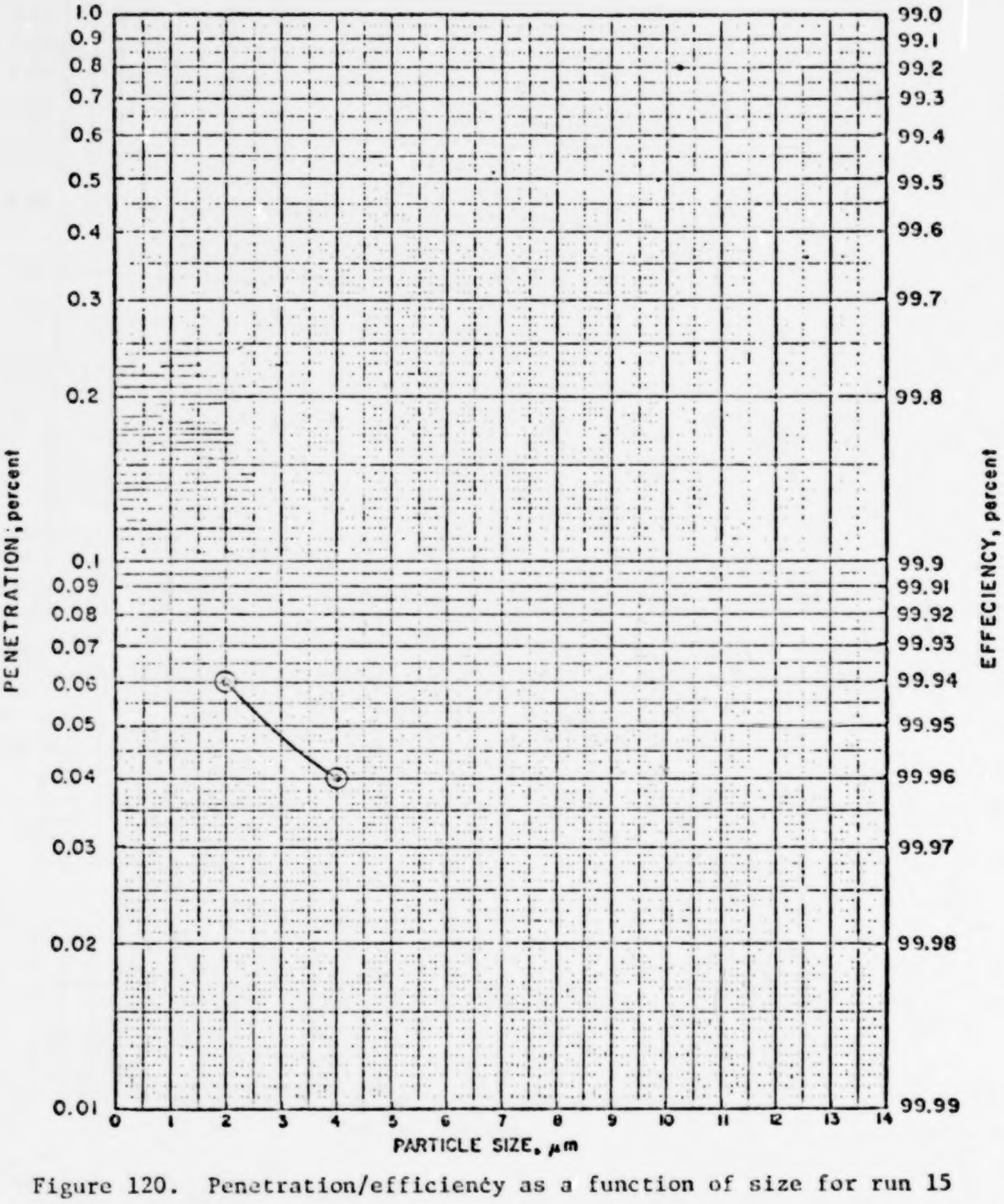

Figure 120. Penetration/efficiency as a function of size for run 15

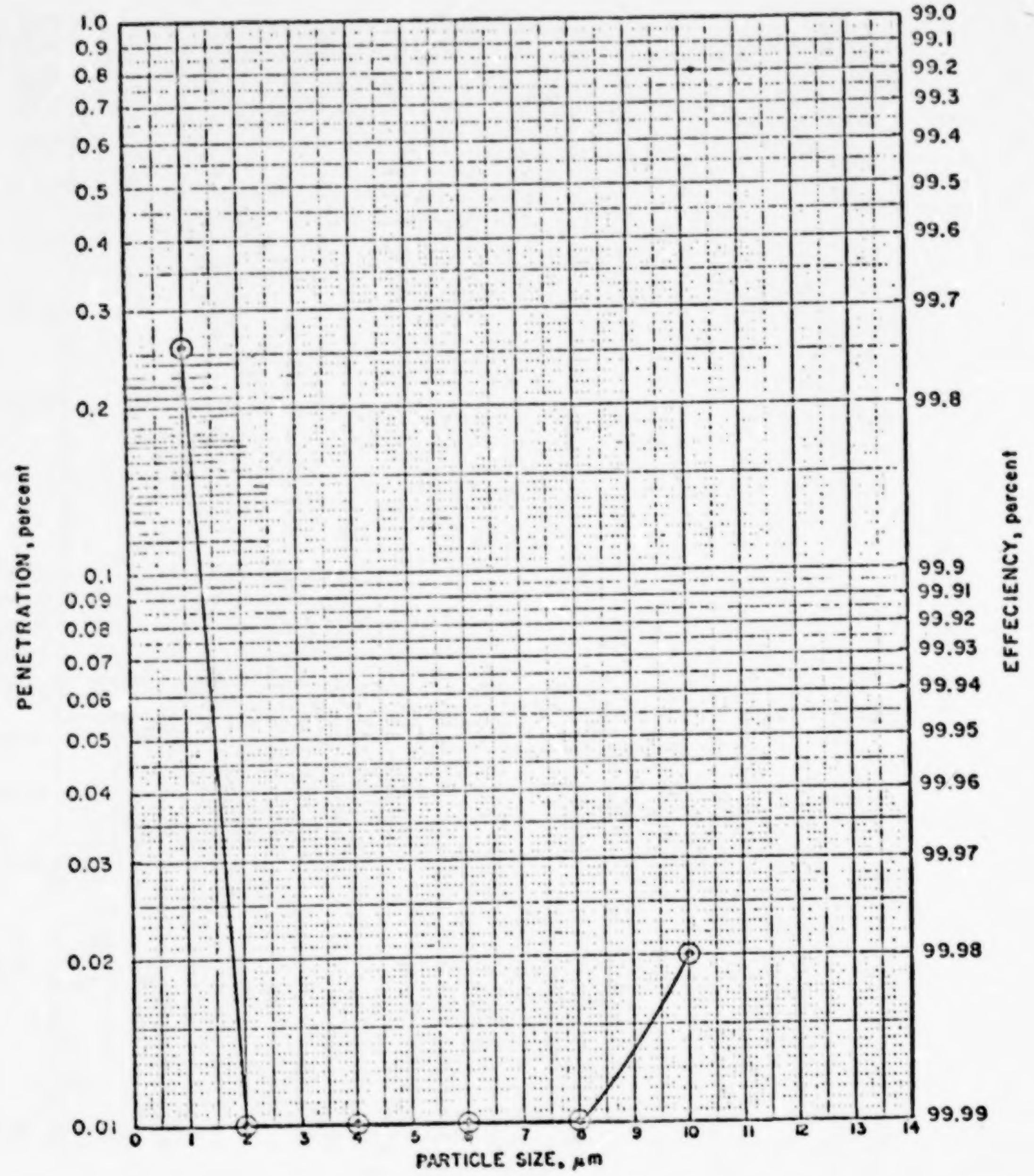

Figure 121. Penetration/efficiency as a function of size for run 16

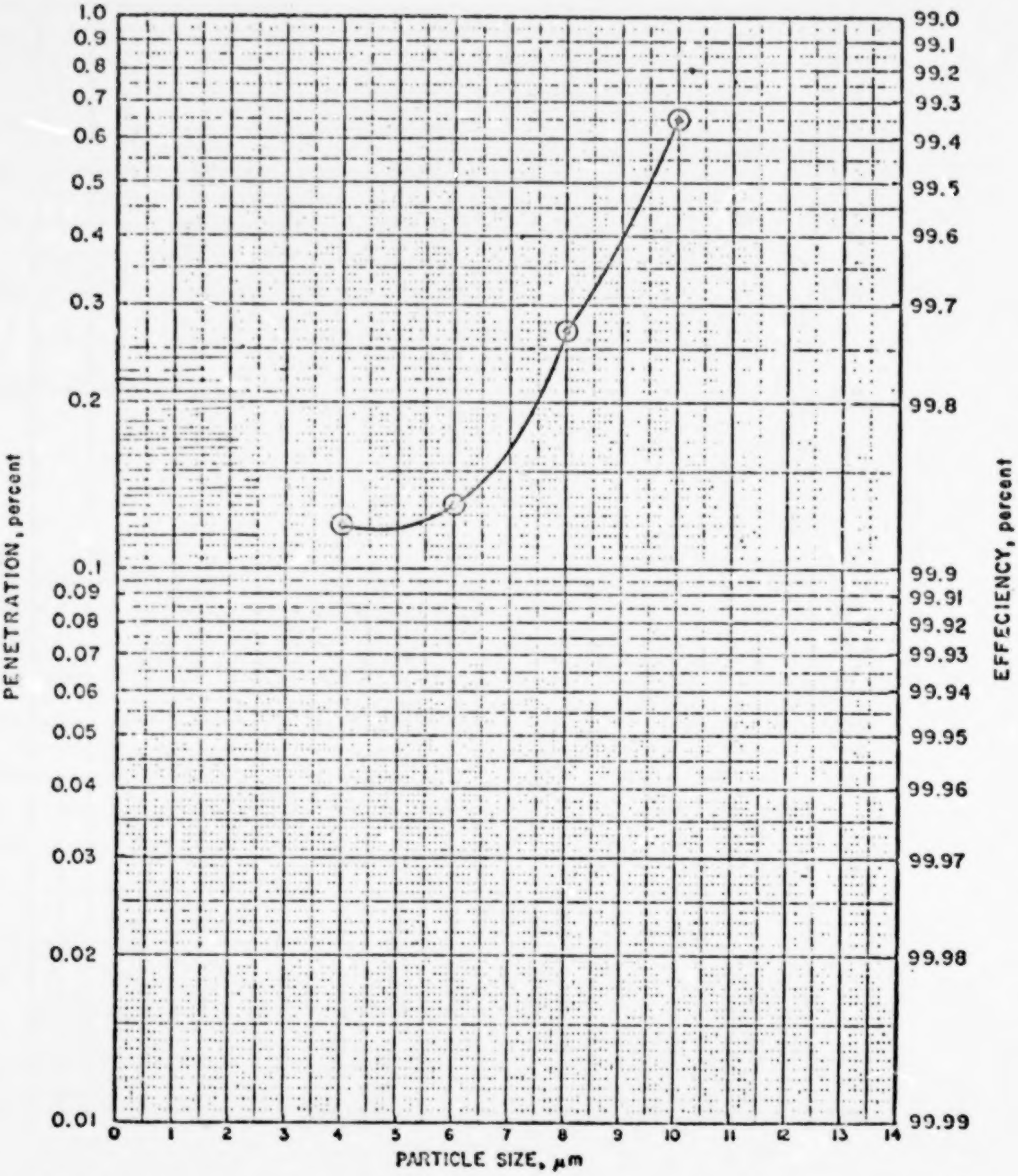

Figure 122. Penetration/efficiency as a function of size for run 17

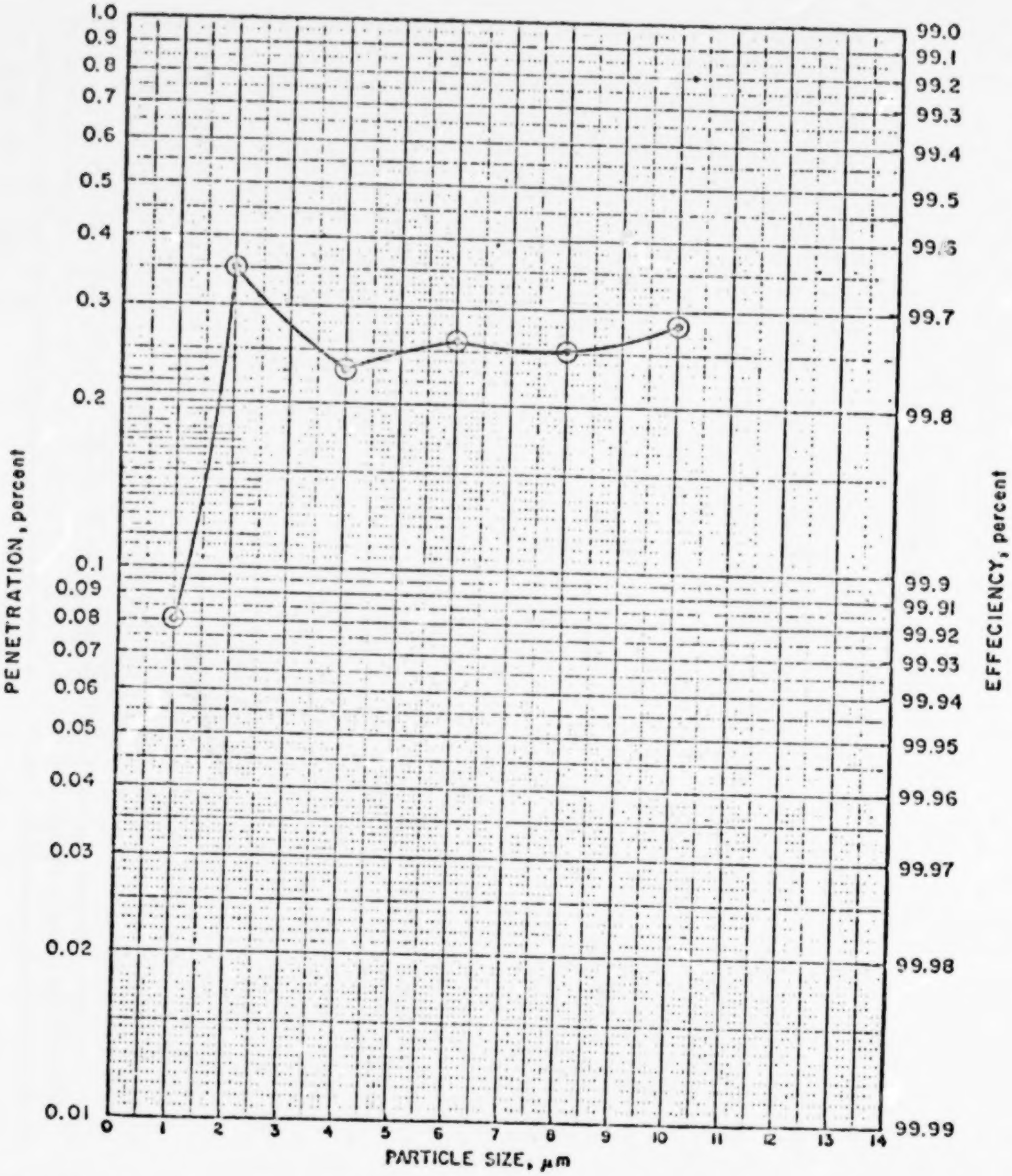

Figure 123. Penetration/efficiency as a function of size for run 18

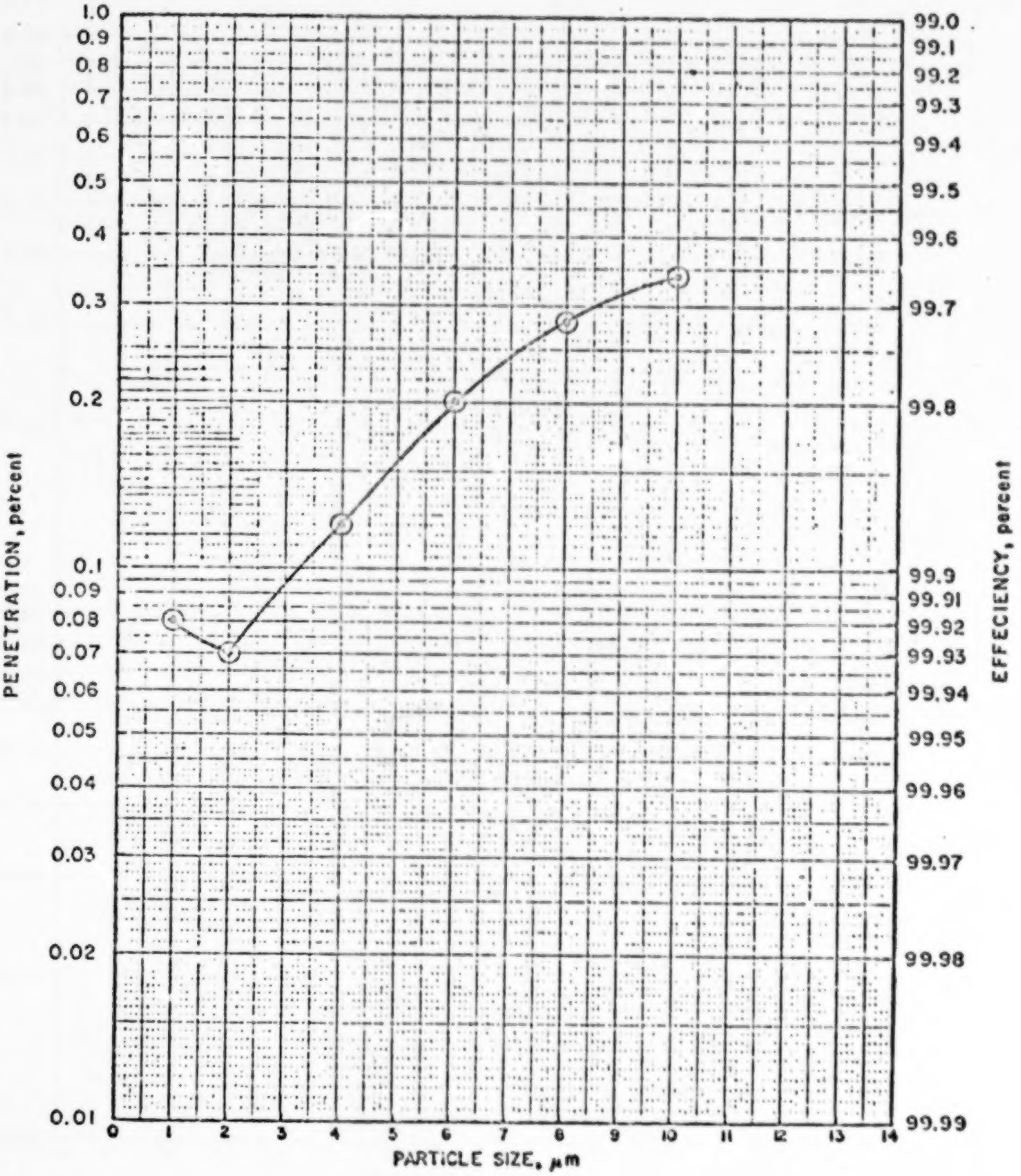

Figure 124. Penetration/efficiency as a function of size for run 19

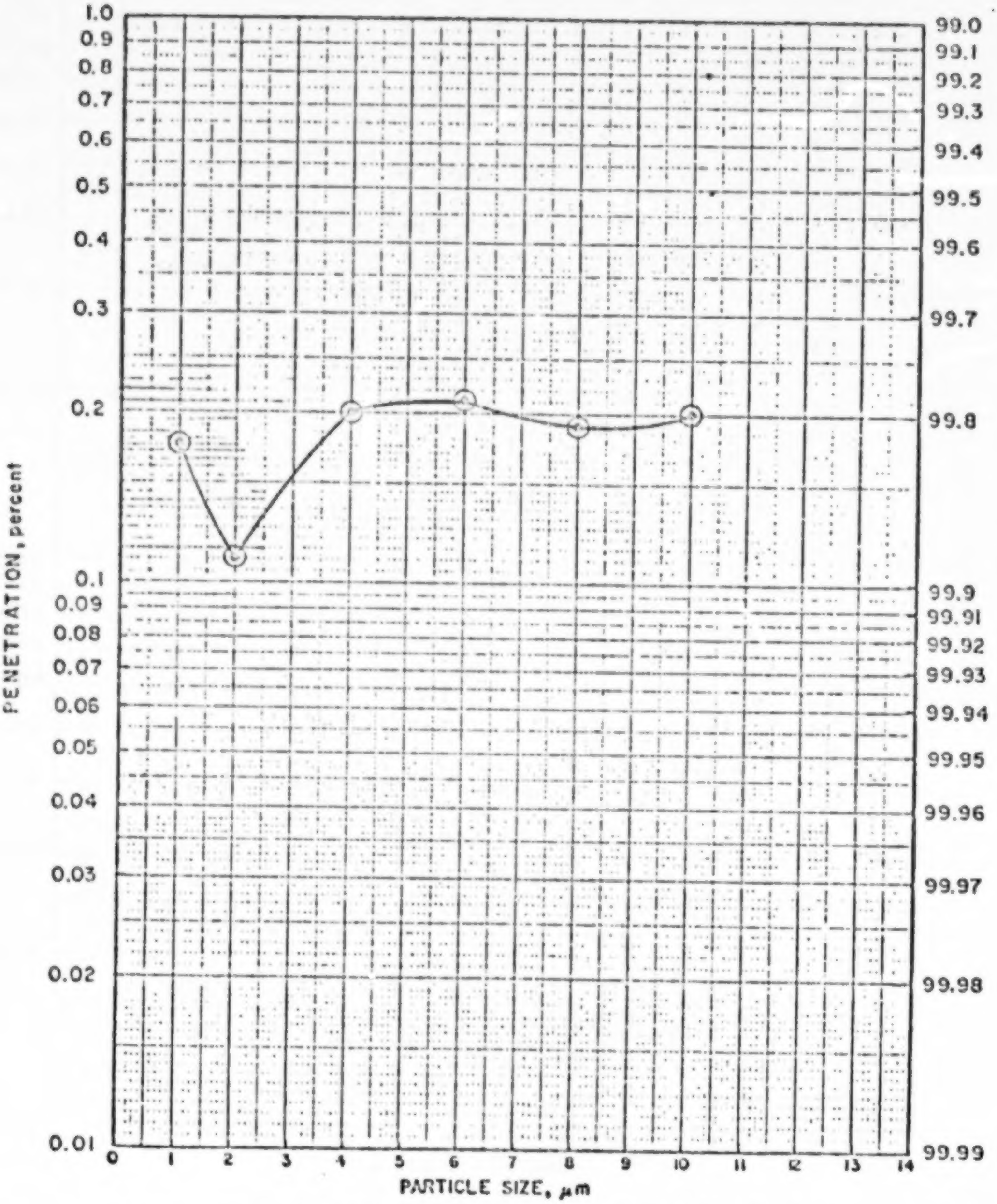

Figure 125. Penetration/efficiency as a function of size for run 20

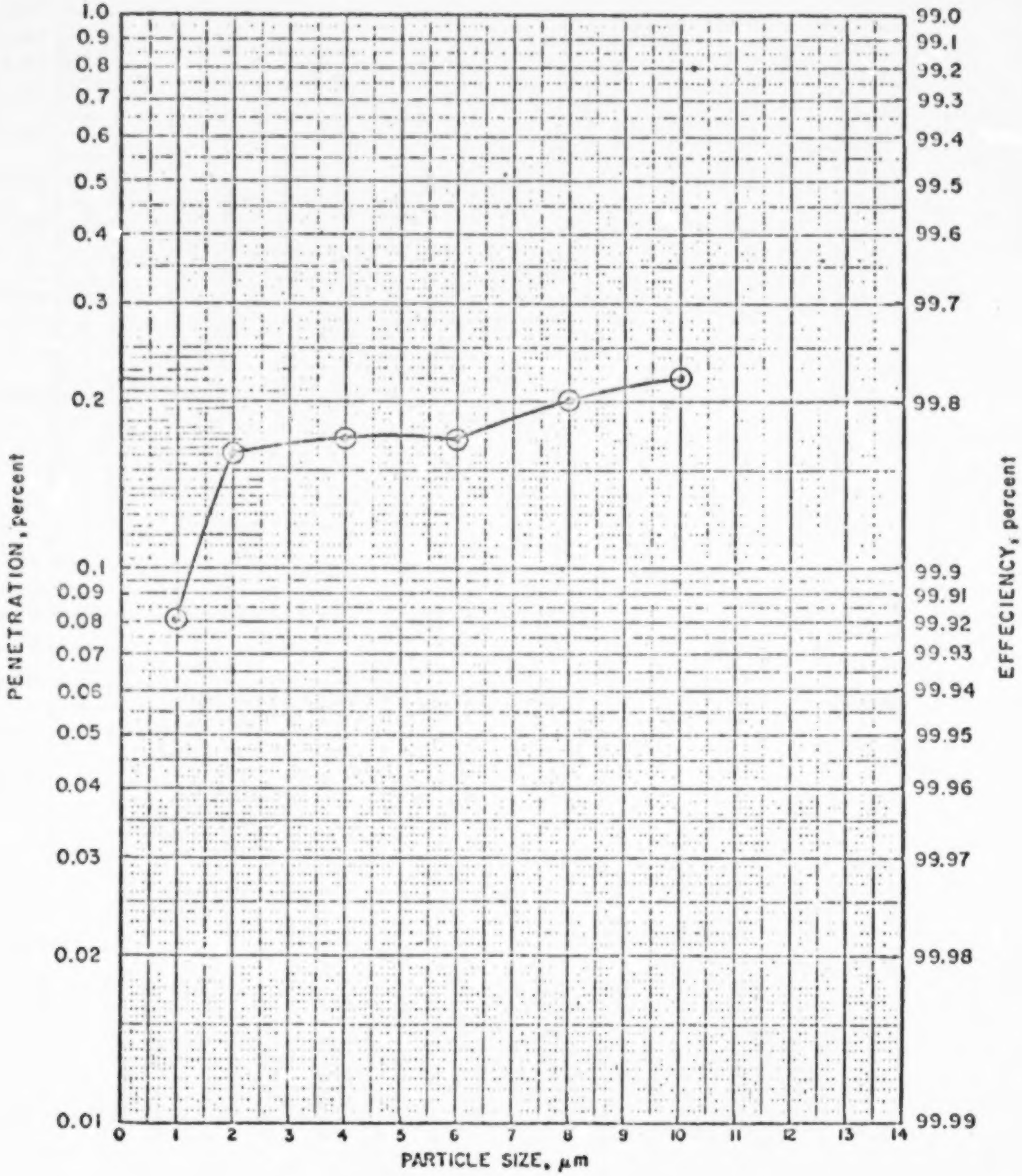

Figure 126. Penetration/efficiency as a function of size for run 21

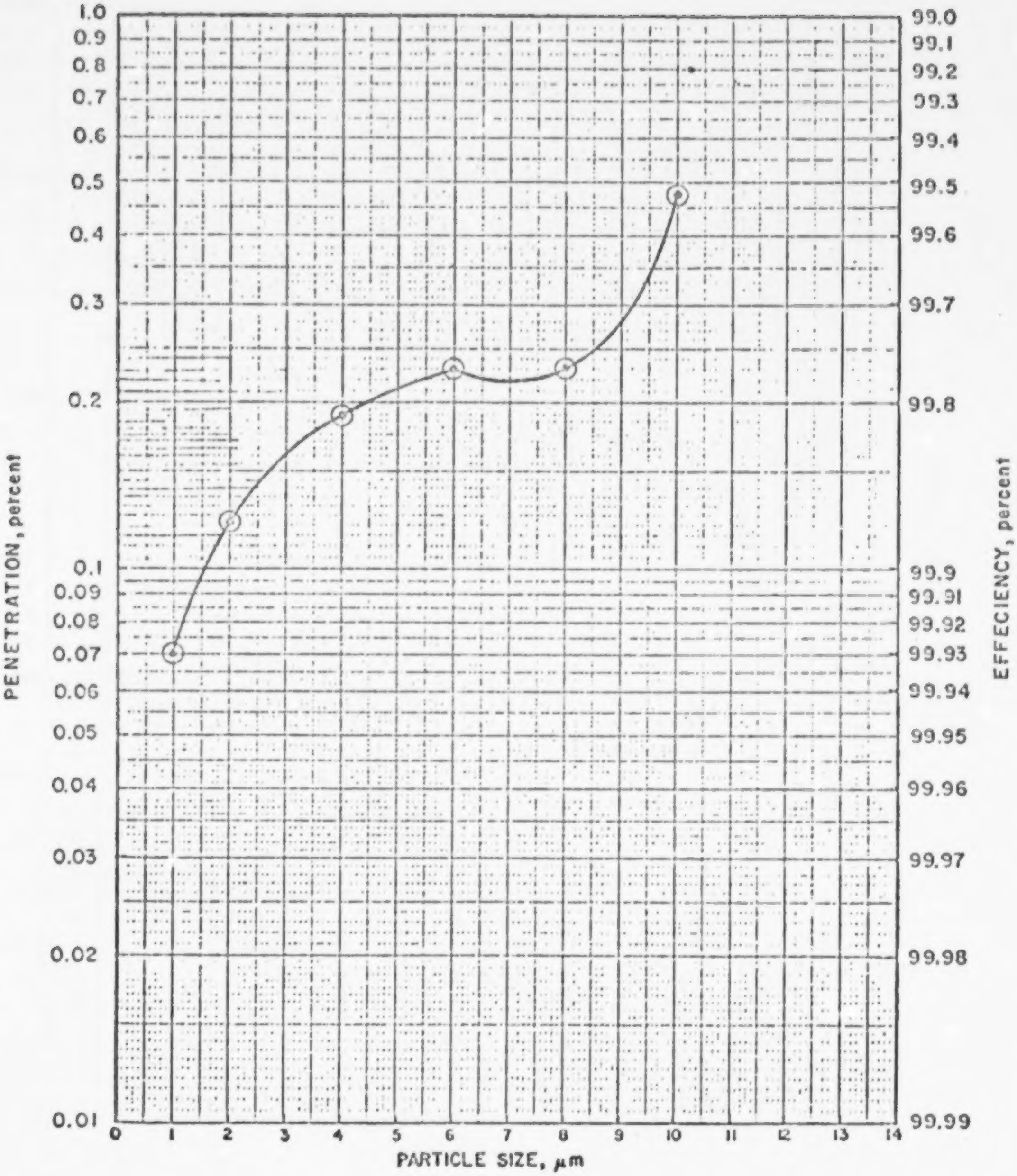

Figure 127. Penetration/efficiency as a function of size for run 22

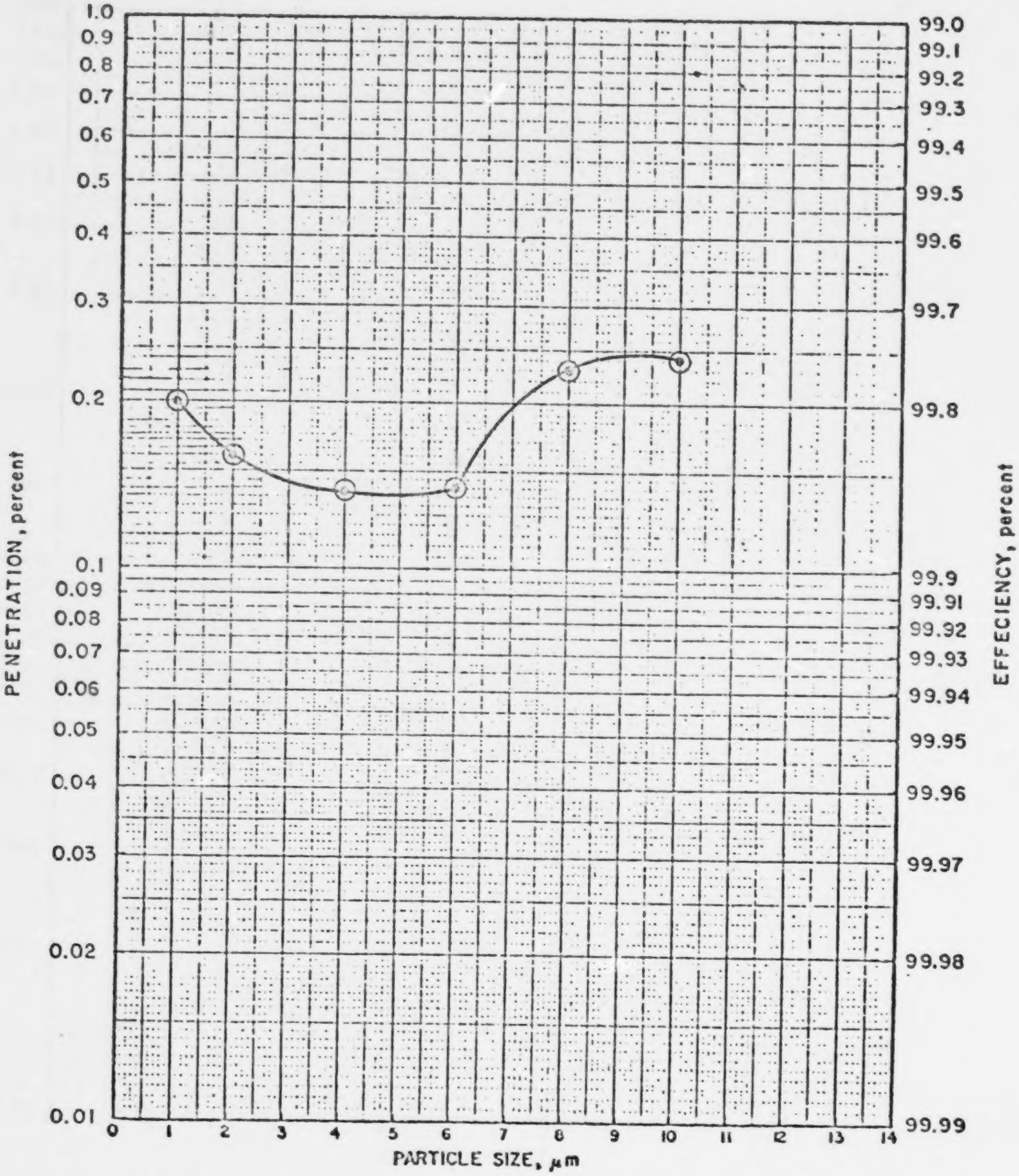

Figure 128. Penetration/efficiency as a function of size for run 23

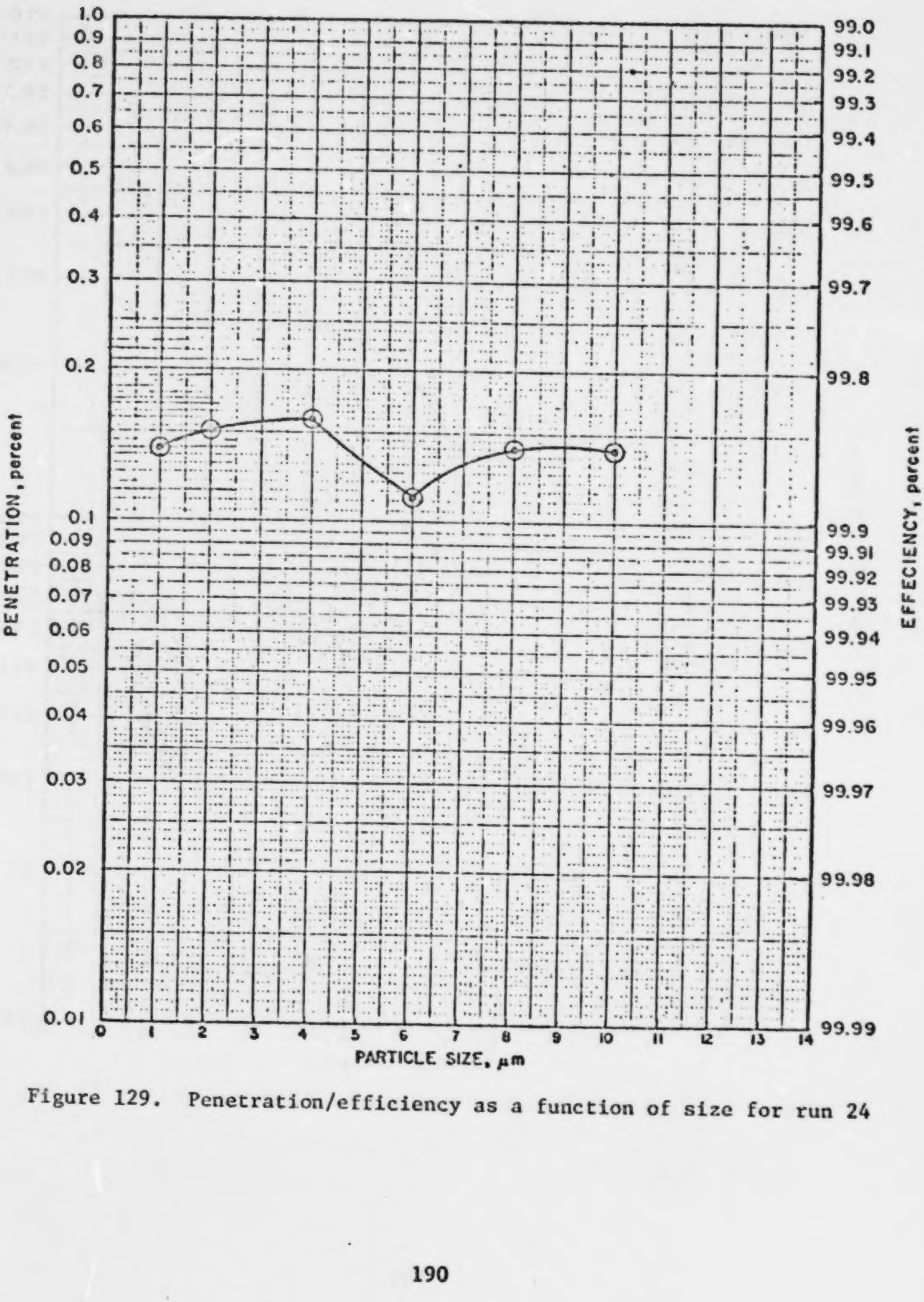

Figure 129. Penetration/efficiency as a function of size for run 24

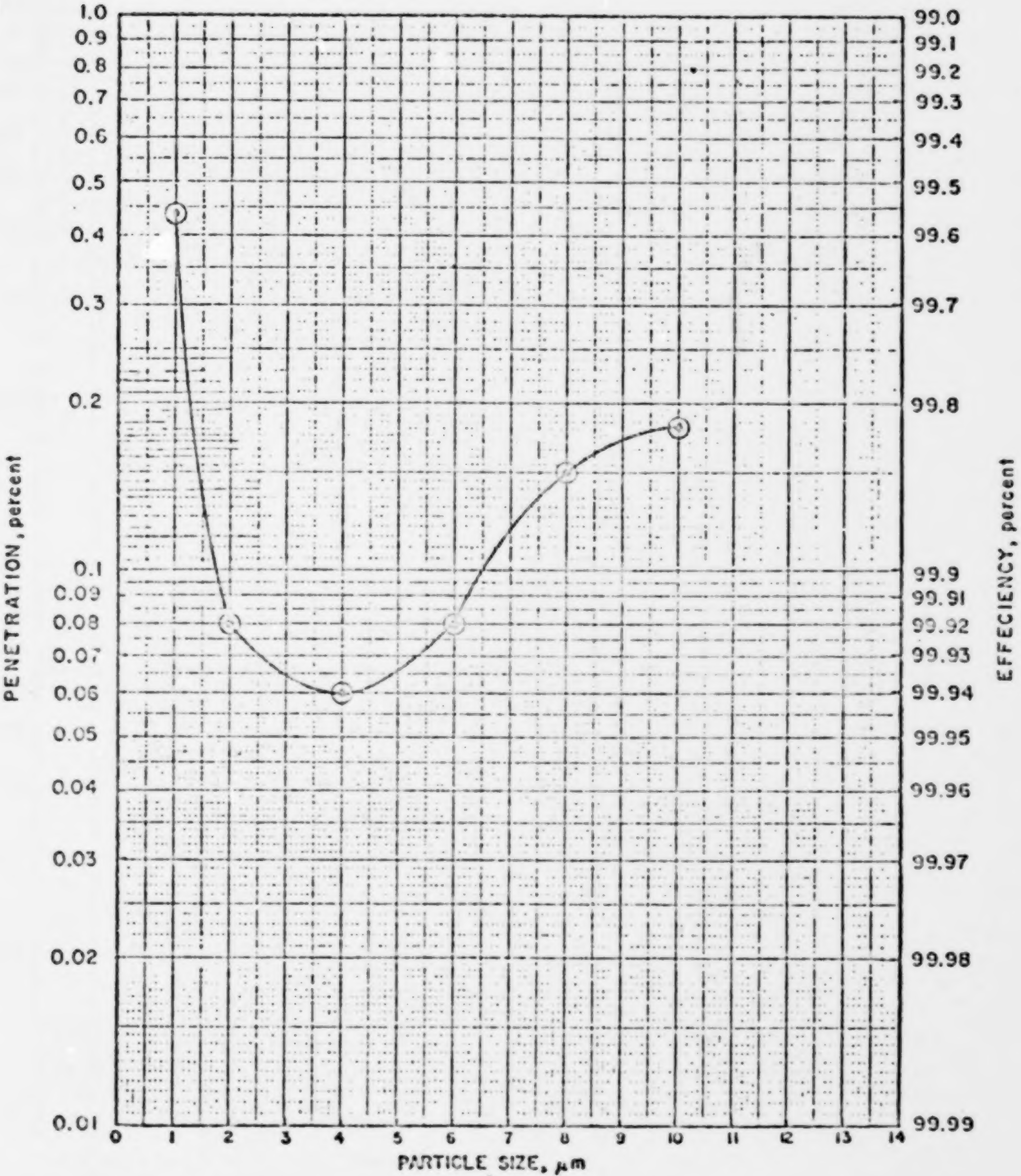

Figure 130. Penetration/efficiency as a function of size for run 25

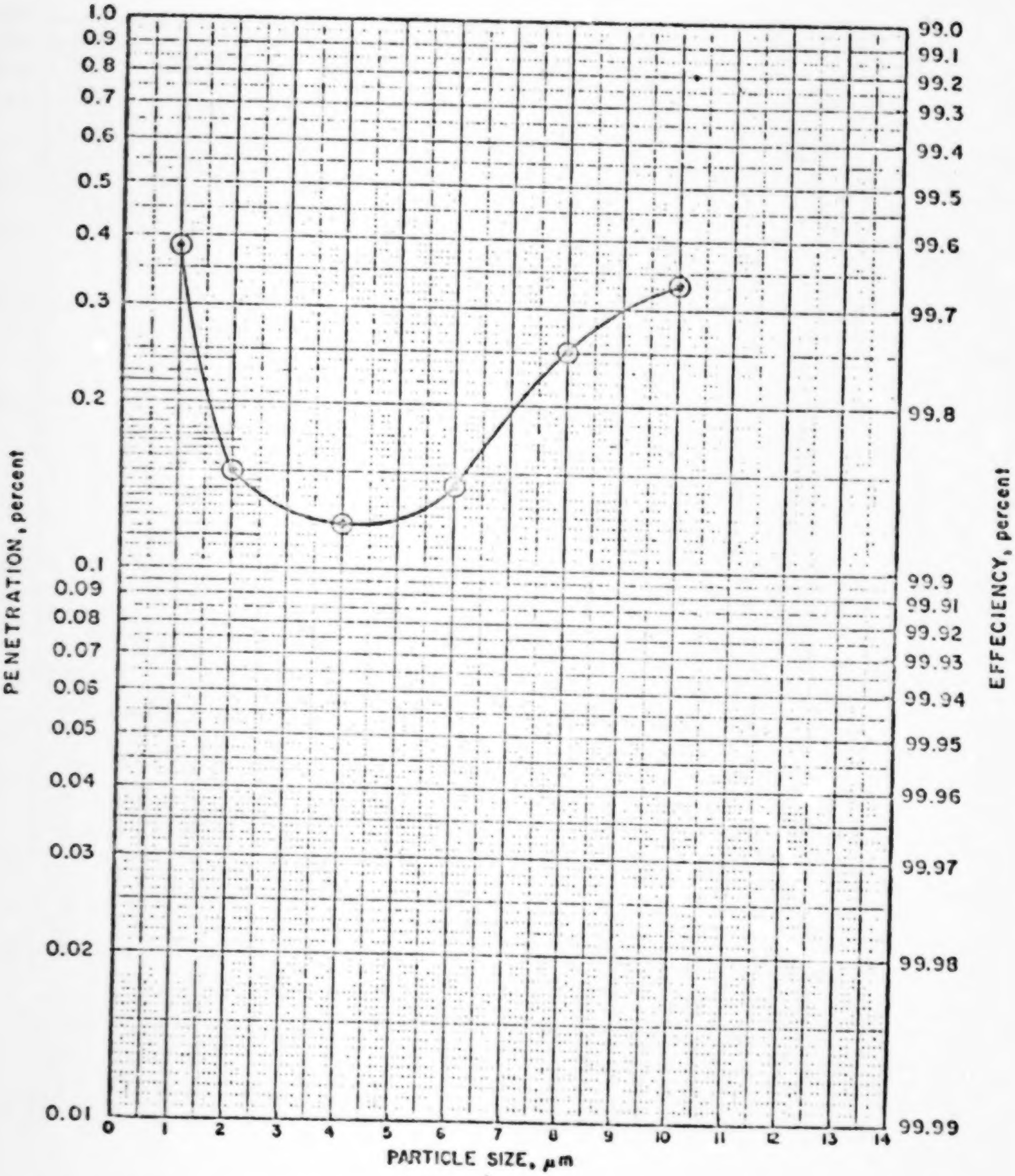

Figure 131. Penetration/efficiency as a function of size for run 26

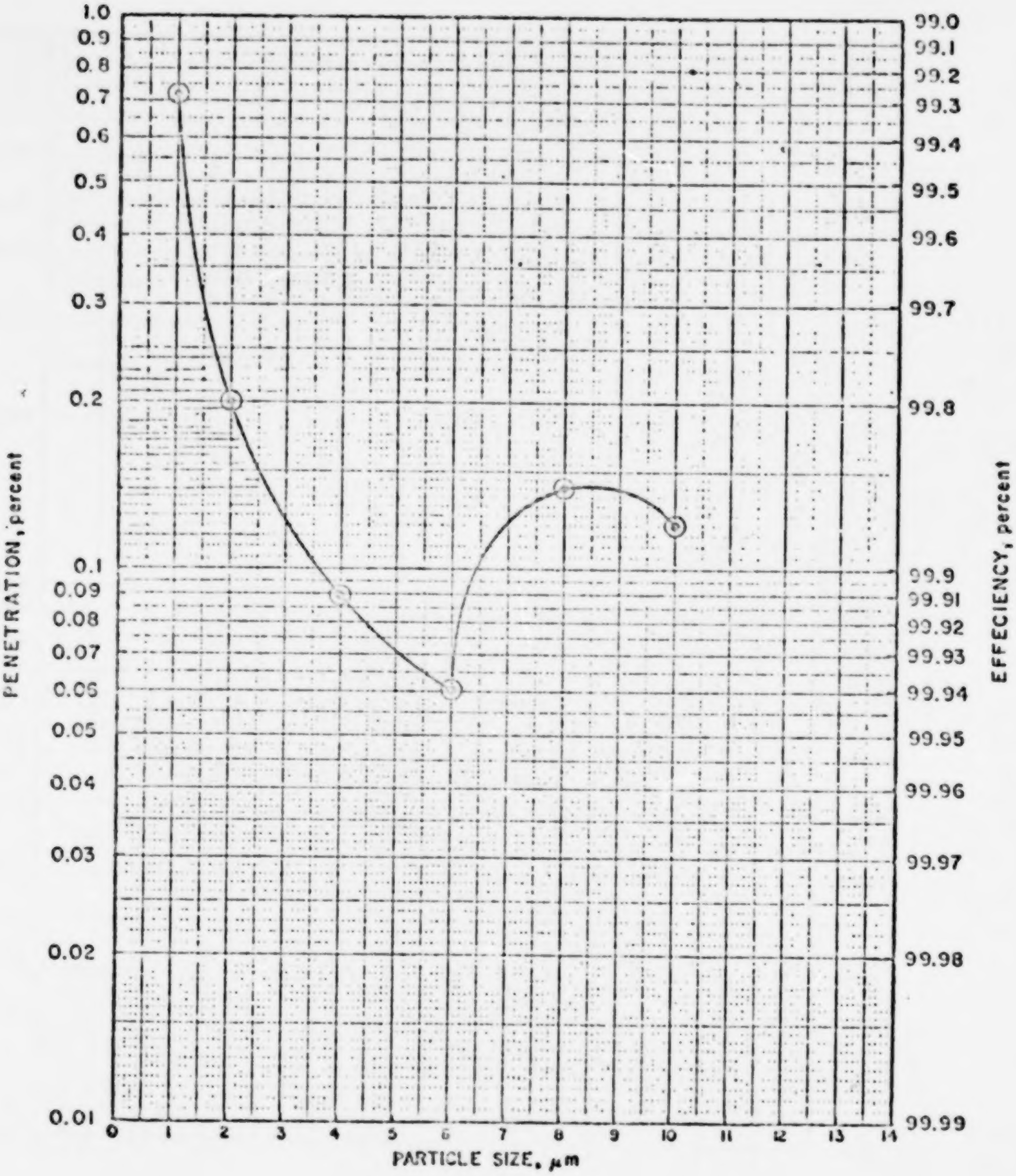

Figure 132. Penetration/efficiency as a function of size for run 27

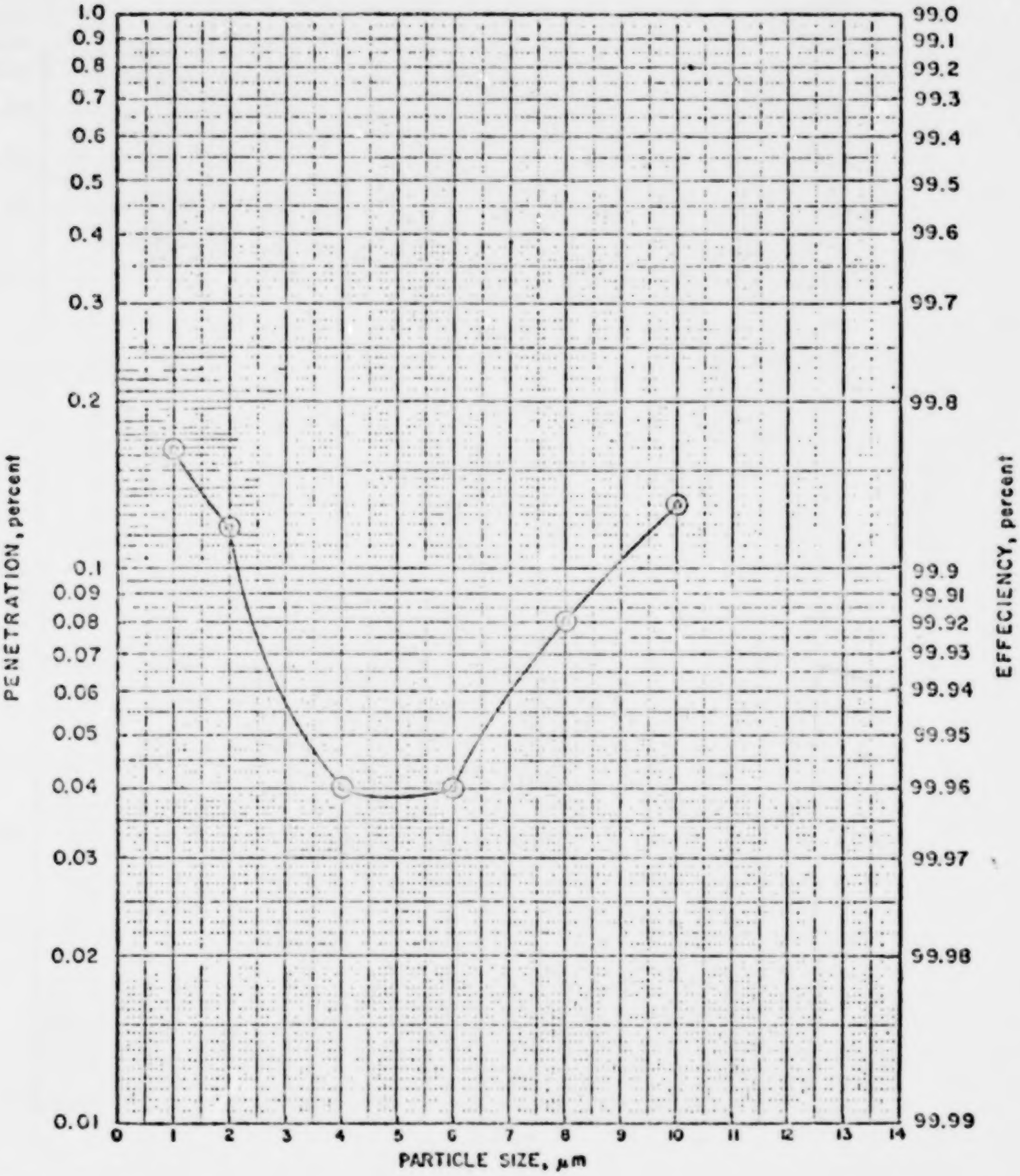

Figure 133. Penetration/efficiency as a function of size for run 28

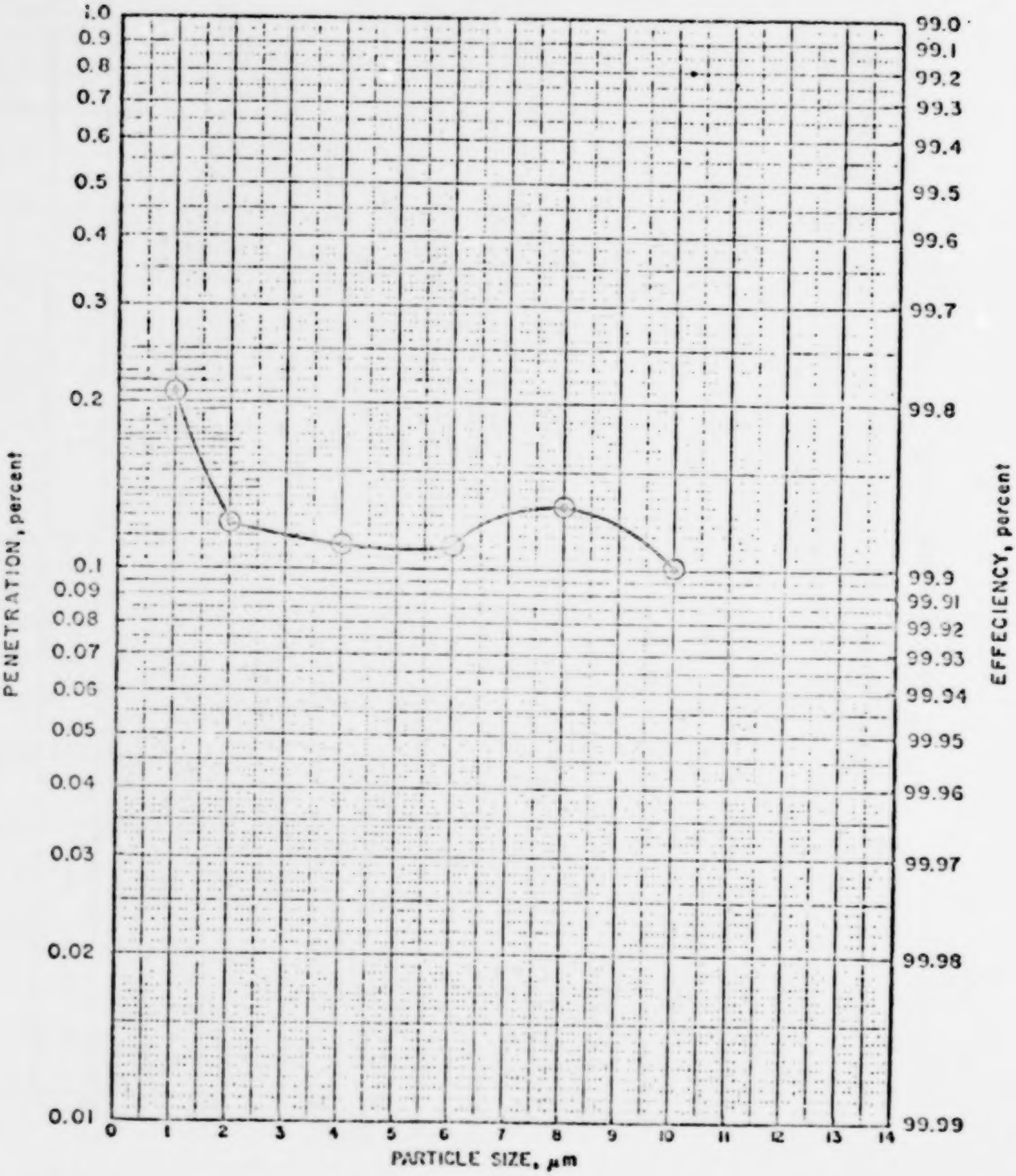

Figure 134. Penetration/efficiency as a function of size for run 29

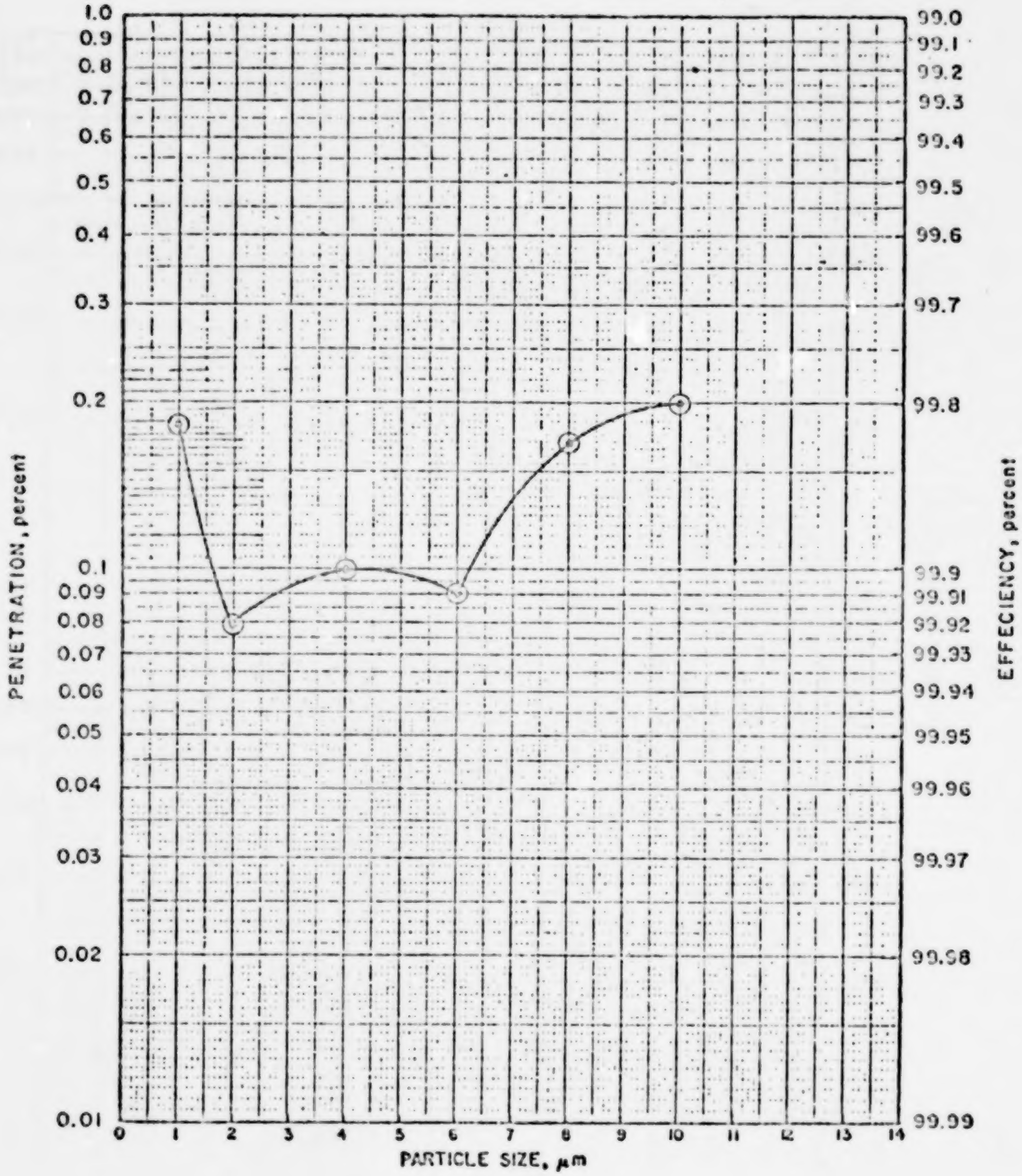

Figure 135. Penetration/efficiency as a function of size for run 30

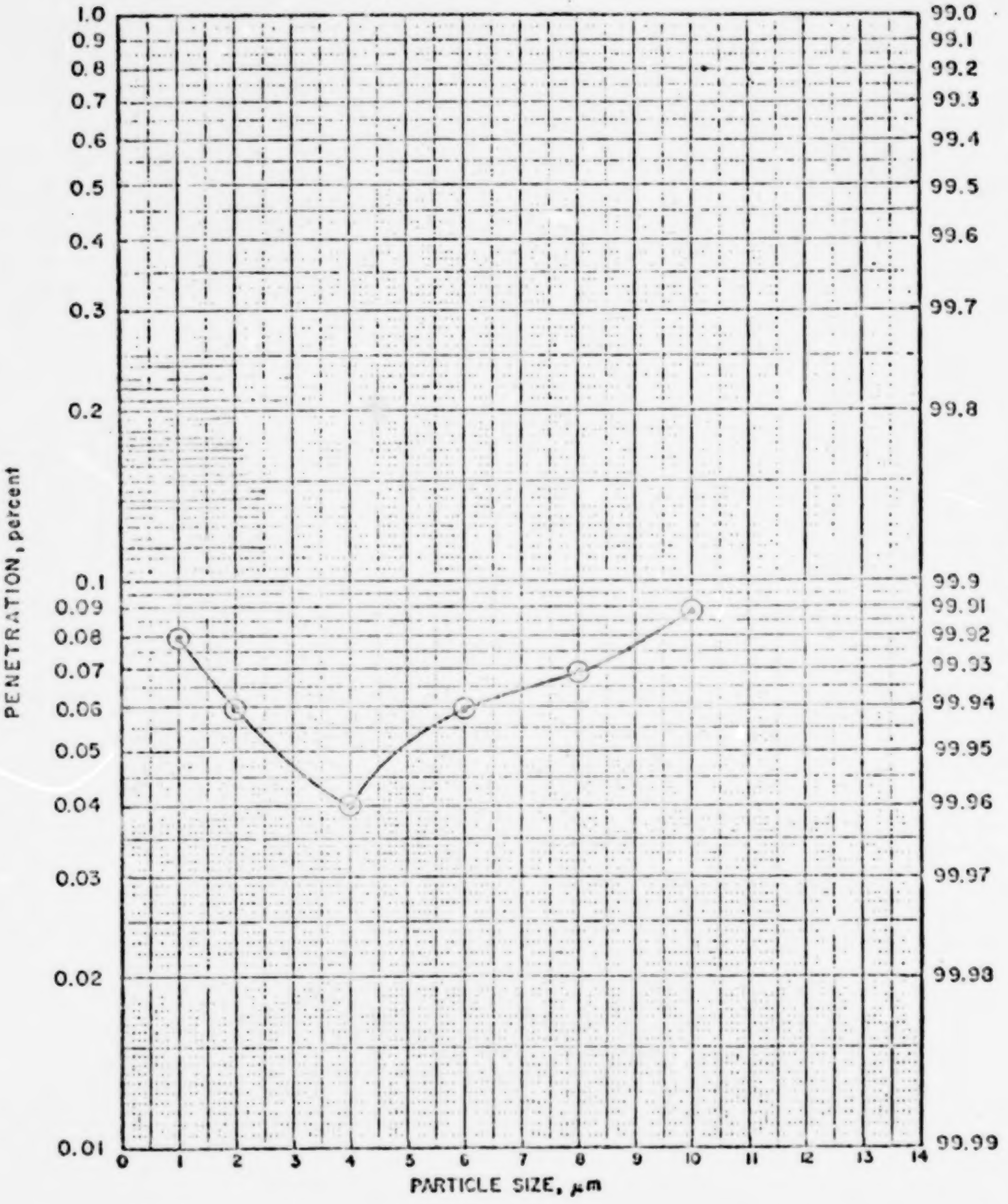

Figure 136. Penetration/efficiency as a function of size for run 31

APPENDIX D

CONDENSATION NUCLEI COUNTER SYSTEM DATA

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Table 25. CONDENSATION NUCLEI COUNTER SYSTEM DATA

Run no.	Time	Inlet concentration,[a] particles/cc	Outlet concentration,[a] particles/cc	Dilution system	Dilution ratio	DD flow, cc/sec
7	0850		1,000	D[b]	5.7	
	0900		1,000	D	5.7	
	0915		2,000	D	5.7	
	1006		4,000	D	7.5	
	1037		1,000	D	7.5	
	1142		600	D	3.6	
	1350		12,000,000	D	1.7	
	1400		45,000,000	D	3.0	
8	0915		33,000	D + AE[c]	47.0	
	0945		210,000	D + AE	35.4	
	1123		1,400,000	D + AE	34.7	
	1155		6,500,000	D + AE	28.5	
	1205		4,200,000	D + AE	34.6	
	1217		24,000	D + AE	47.1	
	1240		5,100,000	D + AE	28.5	
	1305		5,800,000	D + AE	29.1	
	1312		8,900,000	D + AE	32.8	
	1317		7,400,000	D + AE	35.3	
	1332		7,500,000	D + AE	41.8	
	1356		2,900,000	D + AE	43.2	
9	0920		3,200,000	D + AE	17.7	
	0935		4,700,000	D + AE	12.7	
	0945		64,000	D + AE	91.6	
	1005		29,000	D + AE	48.8	
	1025		19,000,000	D + AE	31.4	
	1045		1,500,000	D + AE	24.9	
	1055		48,000,000	D + AE	21.7	
	1125		42,000,000	D + AE	18.9	
	1135		39,000,000	D + AE	17.0	
	1140		29,000,000	D + AE	15.4	
	1147		28,000,000	D + AE	14.0	
	1155		20,000,000	D + AE	10.2	
	1209		21,000,000	D + AE	14.0	
	1223		26,000,000	D + AE	21.7	
	1237		2,200,000	D + AE	31.4	
	1251		8,700,000	D + AE	24.9	
	1300		12,000,000	D + AE	21.7	
	1306		14,000,000	D + AE	14.0	
	1308		14,000,000	D + AE	10.2	
	1309		13,000,000	D + AE	14.0	
	1316		8,700,000	D + AE	21.7	
	1320		14,000,000	D + AE	14.0	
	1326		16,000,000	D + AE	10.2	

Table 25 (continued). CONDENSATION NUCLEI COUNTER SYSTEM DATA

Run no.	Time	Inlet concentration, particles/cc	Outlet concentration, particles/cc	Dilution system	Dilution ratio	DD/flow, cc/sec
9	1454		28,000,000	D + AE	163.1	
	1518		7,800,000	D + AE	164.0	55
	1548		301,000	D + AE + CT[d]	1505.0	55
	1555		35,800,000	D + AE + CT	1194.0	
	1605		25,800,000	D + AE	151.3	
10	0805		276,000,000	D + AE	184.34	
	0820		118,000,000	D + AE + CT	2572.5	
	0850		108,000,000	D + AE + CT	2847.2	
	0912		50,000,000	D + AE + CT	2762.1	
	0923		61,000,000	D + AE + CT	2762.1	
	1040		397,000,000	AE + CT	90.24	
	1058		28,000,000	AE	6.15	
	1105		33,000,000	AE	6.15	55
	1110		2,000,000	AE + CT	61.5	5.5
	1353		1,000,000	AE + CT	50.25	6.5
12	0952		3,000,000	D + AE	131.43	
	1020		74,000	D + AE	73.76	
	1040		180,000	D + AE	72.89	
	1205		105,000	D + AE	70.13	
	1311		6,000,000	D + AE	75.9	
	1350		13,000,000	D + AE	133.0	
	1507		6,000,000	D + AE	126.7	
	1603		309,000,000	D + AE	85.95	
	1645		4,500,000	D + AE	212.7	
	1700		716,000,000	D + AE	162.8	
	1712		780,000,000	D + AE	162.8	
13	0945		835,000,000	D + AE	160.6	
	1015		747,000,000	D + AE	158.9	
	1115		710,000,000	D + AE	154.3	
	1136		785,000,000	D + AE	167.0	
	1150		660,000,000	D + AE	137.6	
	1210		575,000,000	D + AE	130.7	
	1225		589,000,000	D + AE	131.0	
	1235		341,000,000	D + AE	83.2	
	1625		8,000,000	D + AE	150.0	
	1635		45,000	D + AE	150.0	50
	1648		6,000,000	D + AE	140.9	
14	0955		86,000	D + AE	214.2	
	1020		905,000	D + AE	226.3	
	1022		2,000,000	D + AE	226.3	
	1028		17,000,000	D + AE	213.8	
	1045		830,000,000	D + AE	206.8	

Table 25 (continued). CONDENSATION NUCLEI COUNTER SYSTEM DATA

Run no.	Time	Inlet concentration, particles/cc	Outlet concentration, particles/cc	Dilution system	Dilution ratio	DD flow, cc/sec
14	1108		1,025,000,000	D + AE	204.9	
	1128		620,000,000	D + AE	200.21	50
	1148		716,000,000	D + AE	198.96	50
	1216		34,000,000	D + AE + CT	1541.0	6.6
	1241		26,000,000	D + AE + CT	1451.5	7.0
	1310		3,966,000,000	D + AE + CT	2644.8	
	1445		901,000,000	D+AE+CT+CT	268.3	
	1630		637,000,000	D+AE+CT+CT	254.6	
15	1035		477,000,000	D + AE + CT	2728.5	
	1114		430,000,000	D + AE + CT	2413.3	
	1241		846,000,000	D + AE + CT	3319.1	
	1247		2,460,000,000	D + AE + CT	2235.2	
	1300		836,000,000	D + AE + CT	3342.9	
	1330		8,967,000,000	D + AE + CT	3112.3	
	1352		10,582,000,000	D + AE + CT	3112.3	
	1425		4,714,000,000	D + AE + CT	3142.4	
	1435		1,072,000,000	D + AE	218.8	
	1442		678,000,000	D + AE	218.8	55
	1458		449,000,000	D + AE	224.4	35
	1505		853,000,000	D + AE	224.4	50
	1522		11,000,000	D + AE + CT	2167.3	5
	1545		40,000,000	D + AE + CT	1077.5	10
	1557		89,000,000	D + AE + CT	496.62	22
	1605		635,000,000	D + AE + CT	352.2	31
	1616		77,000,000	D + AE + CT	773.7	14
	1628		4,000,000	D + AE + CT	1805.3	6
	1636		917,000,000	D + AE	229.2	50
	1641		1,008,000,000	D + AE	229.2	
16	1142		32,000,000	D + AE	10.65	
	1153		47,000,000	D + AE	10.65	
	1247		13,000,000	D + AE	8.06	
17	1612		38,000,000	D + AE	8.04	50
	1616		21,000,000	D + AE	7.59	
	1638		49,000,000	D + AE	7.59	50
	1656		3,500,000	D + AE + CT	70.2	5
	1705		3,600,000	D + AE + CT	73.0	5
	1726		5,400,000	D + AE + CT	78.5	5
18	1222		576,000,000	D + AE	263.5	
	1515		547,000,000	D + AE	227.8	

Table 25 (continued). CONDENSATION NUCLEI COUNTER SYSTEM DATA

Run no.	Time	Inlet concentration, particles/cc	Outlet concentration, particles/cc	Dilution system	Dilution ratio	DD flow, cc/sec
19	1830		748,000,000	D + AE	467.5	
	1905		762,000	D + AE + CT	5079.5	
	1914		25,800,000	D + AE	477.4	
	1925		811,000,000	D + AE	477.4	
	1945		95,500,000	D + AE	477.4	
	2005		573,000,000	D + AE	477.4	
	2022		955,000,000	D + AE	477.4	
20	1050		51,000,000	D + AE	507.9	
	1458		35,000,000	D + AE	580.5	50
21	0826		24,000,000	D + AE	590.4	
	0909		12,000,000	D + AE	590.4	
	0941		4,000,000	D + AE	201.9	
	1200		24,000,000	D + AE	191.6	
	1225		34,500,000	D + AE	191.6	
	1243		30,000,000	D + AE	186.9	
	1251		28,000,000	D + AE	186.9	
23	1340		320,000	AE	10.65	
	1520		1,500,000	AE	12.31	
	1717		927,000	AE	6.18	
24	1312		9,000,000	AE	8.07	
	1346		17,000,000	AE	7.54	
	1537		17,500,000	AE	7.63	
	1738		19,000,000	AE	7.63	
25	1239		2,000,000	AE	8.57	
	1442		2,000,000	AE	10.0	
	1456		2,300,000	AE	9.59	
	1530		2,400,000	AE	10.93	
	1552		2,500,000	AE	10.0	
	1614		2,200,000	AE	10.00	
26	1700		6,500,000	ISD[e] + AE	131.0	
	1733		92,000	ISD + AE	132.3	
	1745		1,200,000	ISD + AE	126.1	
	1808		185,000	ISD + AE	108.1	
	1815		105,000	ISD + AE	150.3	
27	1215		93,000	ISD + AE	93.7	
	1233		67,000	ISD + AE	84.5	
	1441		69,000	ISD + AE	98.7	
	1500		85,000	ISD + AE	97.2	50
	1625		7,600	ISD	12.7	
	1640		52,000	ISD + AE	104.5	

Table 25 (continued). CONDENSATION NUCLEI COUNTER SYSTEM DATA

Run no.	Time	Inlet concentration, particles/cc	Outlet concentration, particles/cc	Dilution system	Dilution ratio	DD/flow, cc/sec
28	1237		272,000	ISD + AE	104.4	
	1340		59,000	ISD + AE	98.5	
	1728		84,000	ISD + AE	105.8	
29	1129		51,000,000	ISD	14.5	
	1600		50,000	ISD + AE	99.4	
30	1222		102,000	ISD + AE	102.2	
	1302		113,000	ISD + AE	113.2	
	1507		71,000	ISD + AE	94.5	
	1525		98,000	ISD + AE	88.9	50
	1533		58,000	ISD + AE	88.9	
	1540		104,000	ISD + AE	94.5	50
	1547		94,000	ISD + AE	94.5	
	1554		115,000	ISD + AE	105.1	
	1617		126,000	ISD + AE	96.9	
	1628		116,000	ISD + AE	96.9	50
	1702		130,000	ISD + AE	92.6	
	1711		111,000	ISD + AE	92.6	50
	1715		111,000	ISD + AE	92.6	
	1718		93,000	ISD + AE	92.6	50
	1721		102,000	ISD + AE	92.6	50
	1725		111,000	ISD + AE	92.6	50
	1728		111,000	ISD + AE	92.6	50
	1732		111,000	ISD + AE	92.6	50
	1737		111,000	ISD + AE	92.6	50
	1750		115,000	ISD + AE	96.1	
31	1204	9,500,000		ISD + AE	2007.0	
	1255	6,700,000		ISD + AE	1732.6	
	1324	3,400,000		ISD + AE	1437.2	
	1410	5,600,000		ISD + AE	1400.3	
	1448	5,500,000		ISD + AE	1583.2	

[a] Concentration = CNC reading (particles/cc) x dilution ratio.

[b] Pump diluter.

[c] Air ejector diluter.

[d] Capillary tube diluter.

[e] In-stack diluter.

APPENDIX E

CONDENSATION NUCLEI COUNTER CHART RECORDINGS

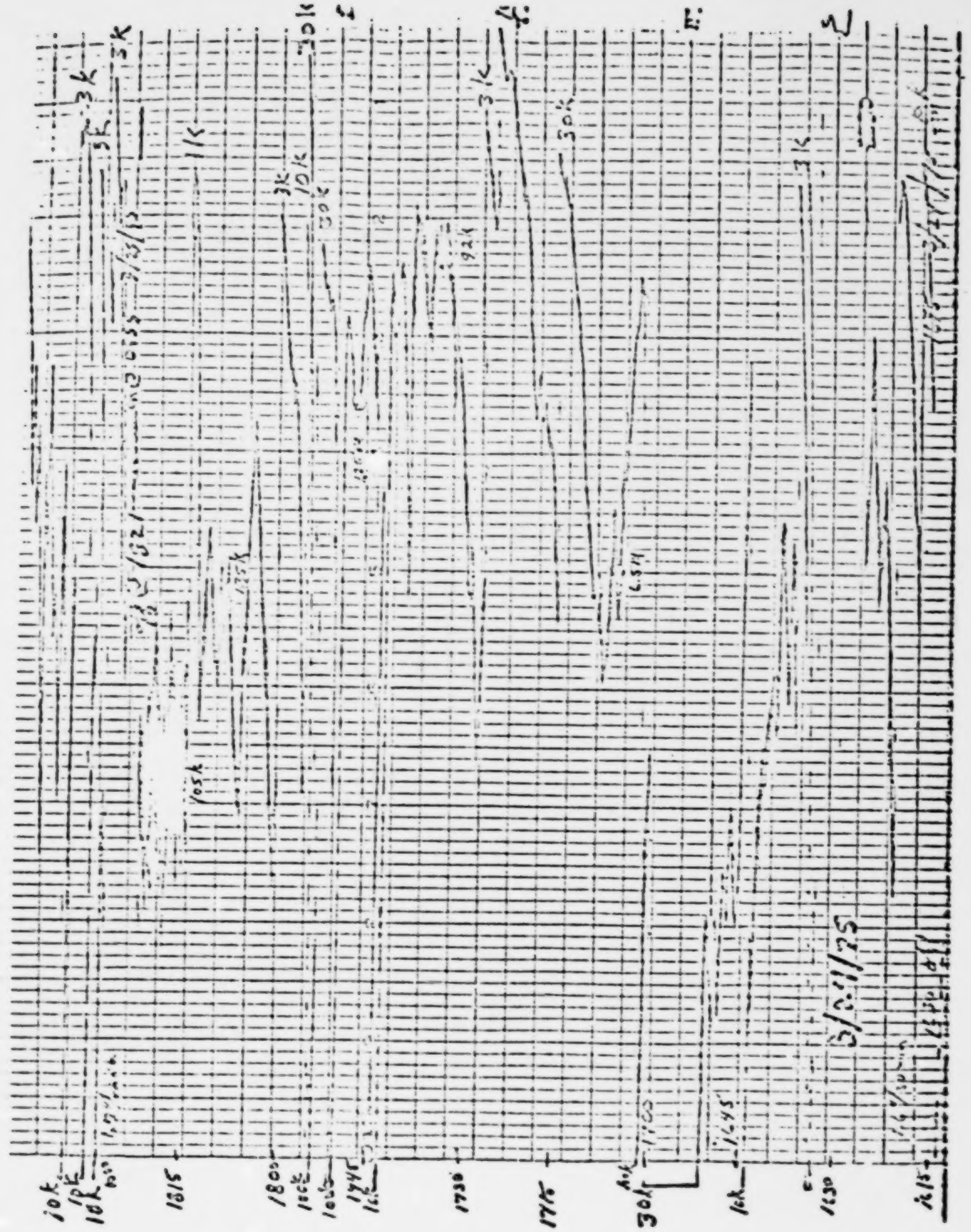

Figure 137. GC chart recording for run 26

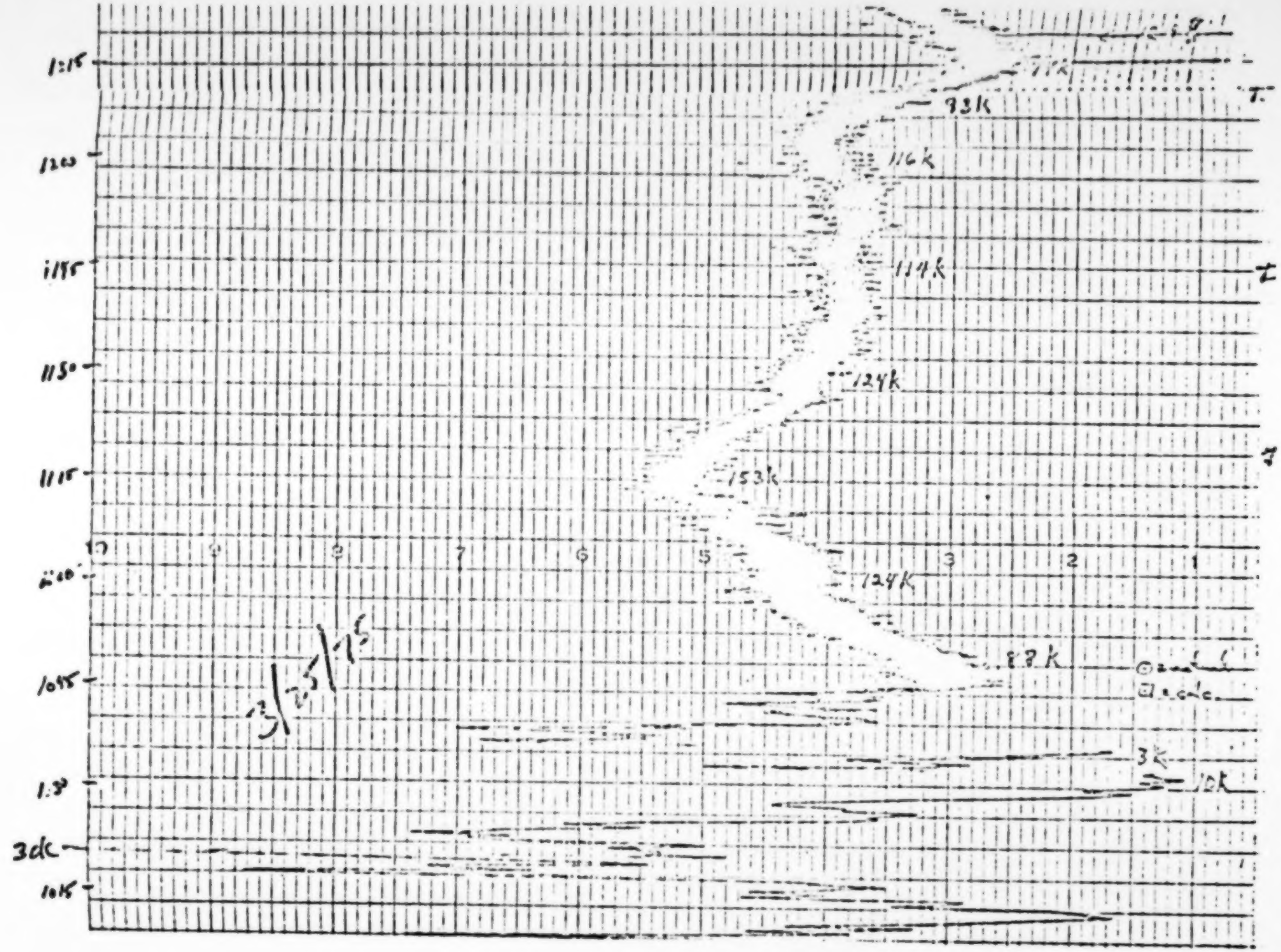

Figure 138. C&C chart recording for run 27

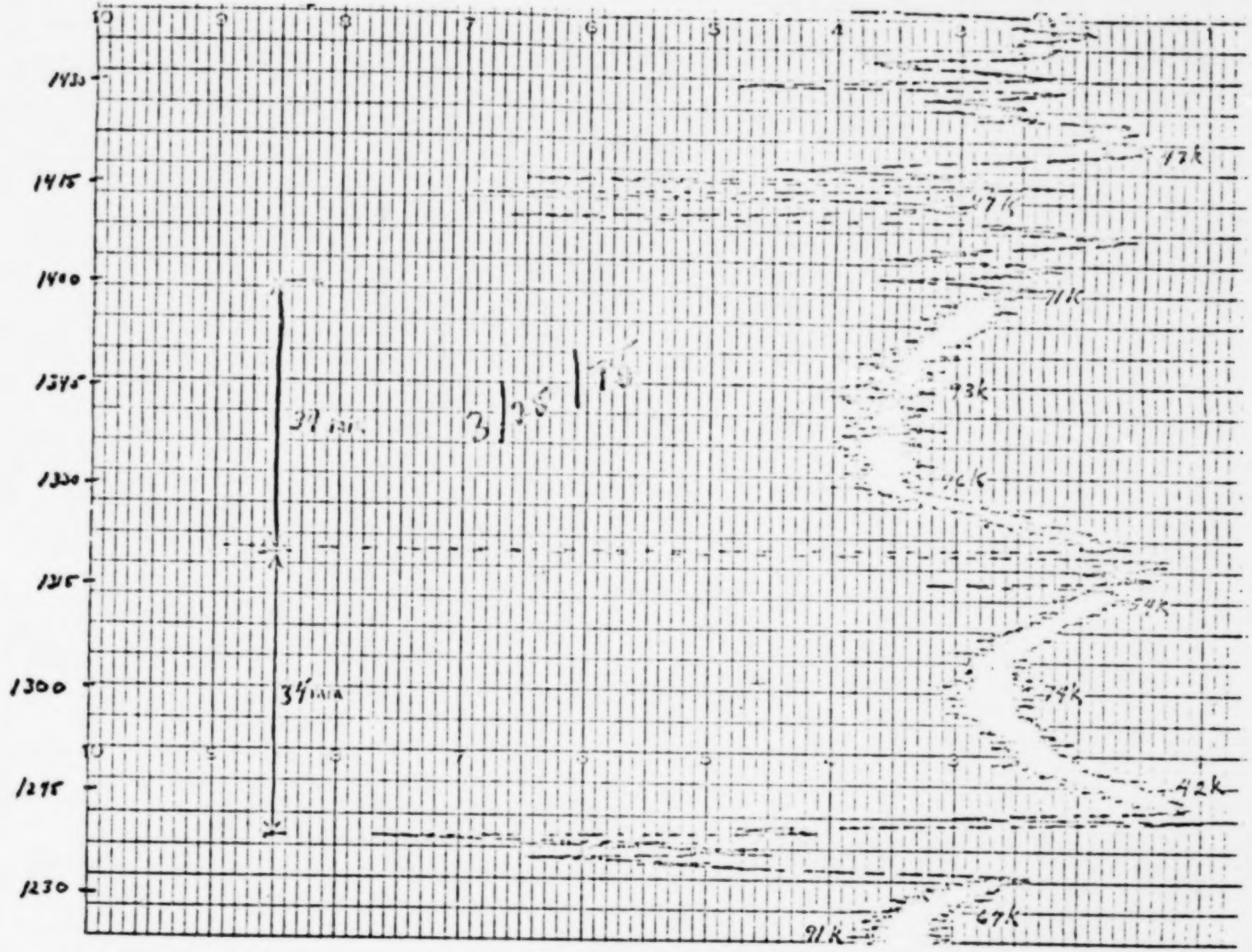

Figure 138 (continued). CNC chart recording for run 27

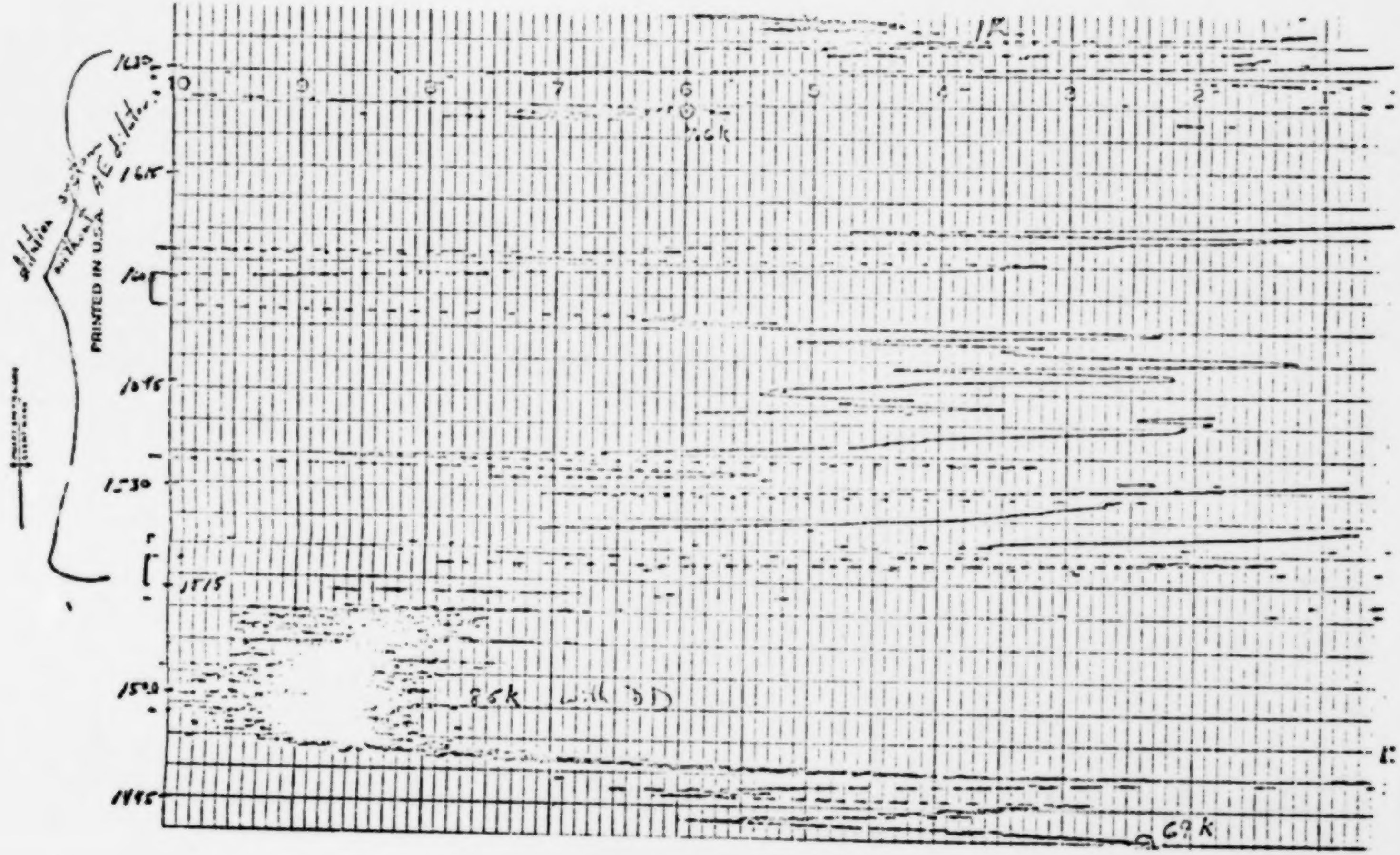

Figure 13d (continued). CNC chart recording for run 27

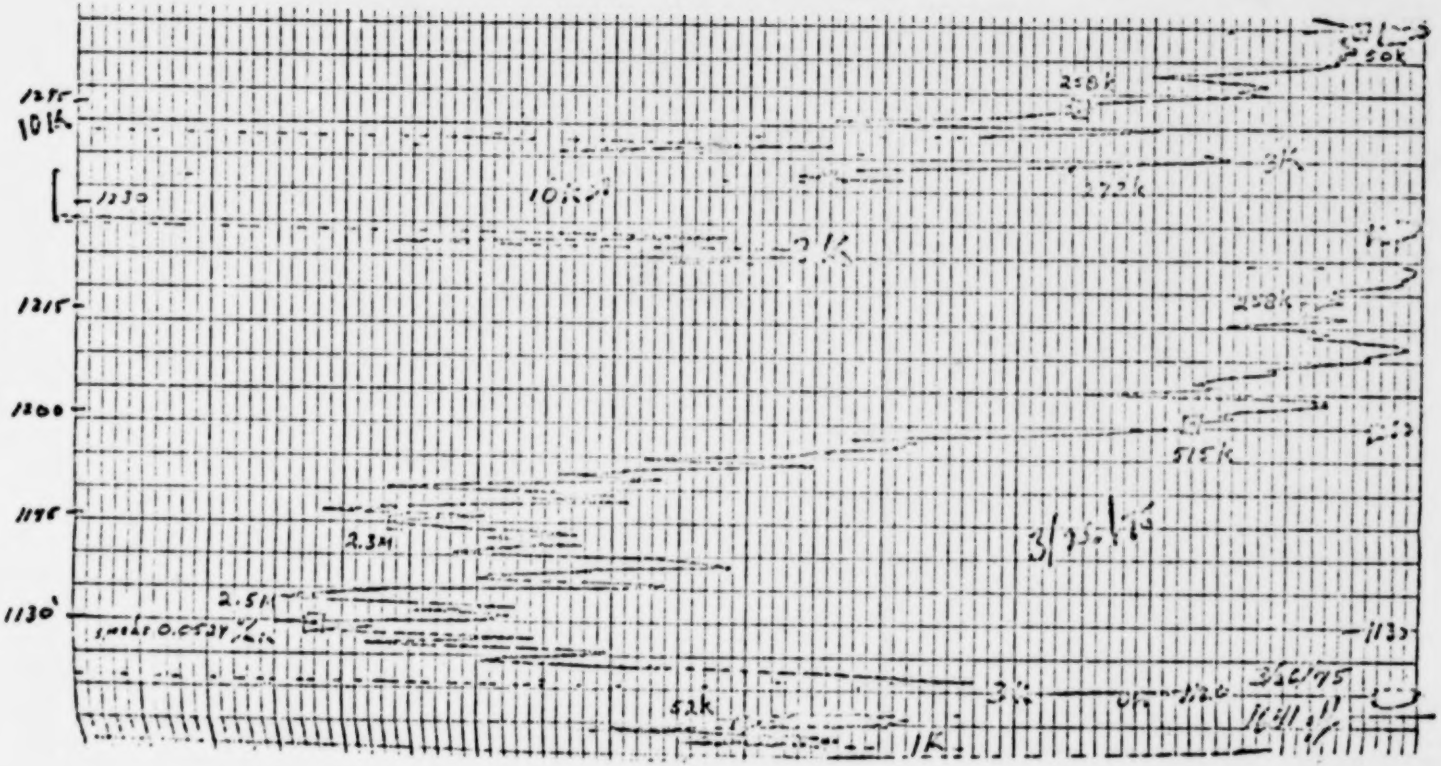

Figure 139. CNC chart recording for run 28

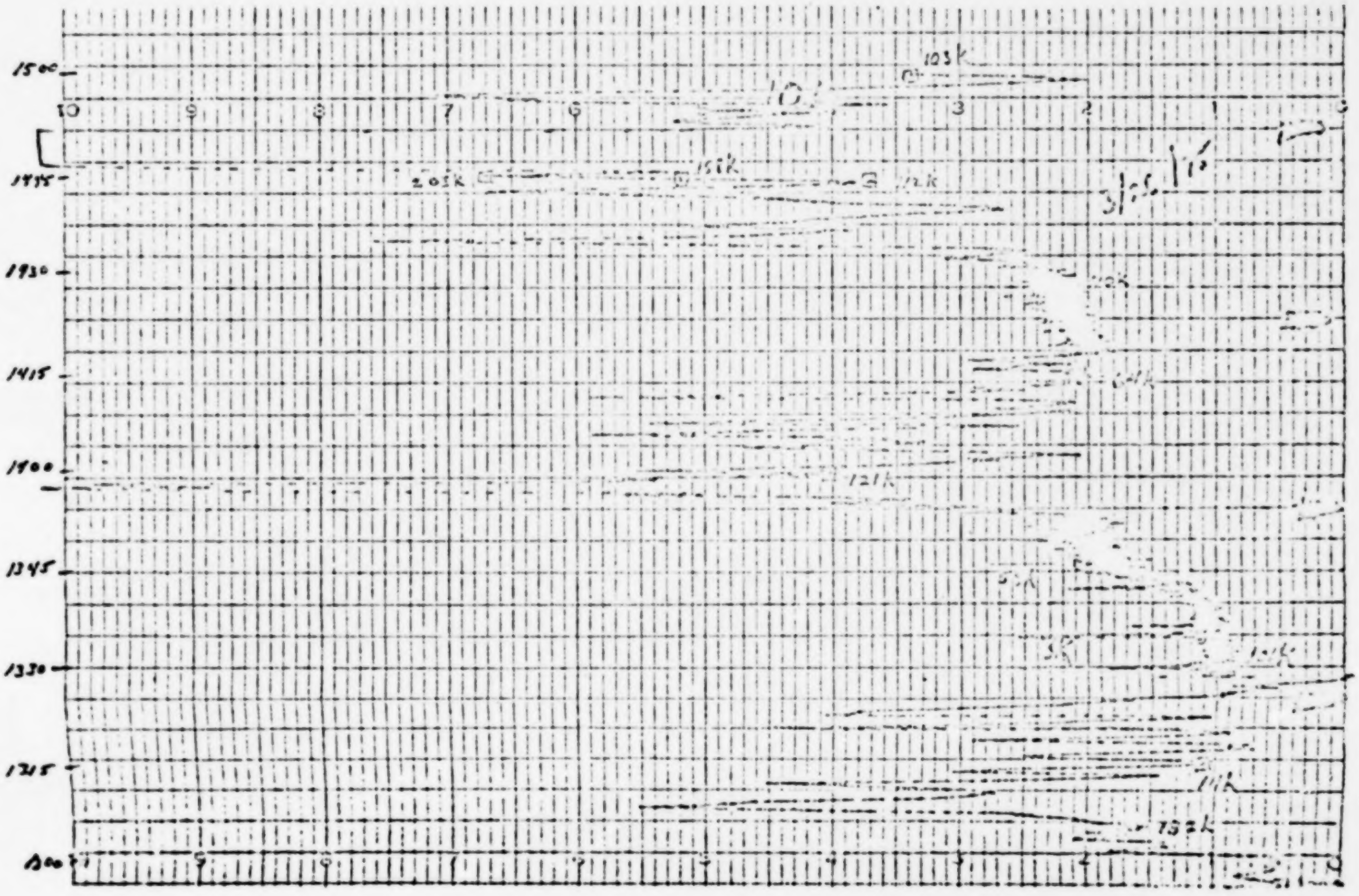

Figure 139 (continued). CNC chart recording for run 28

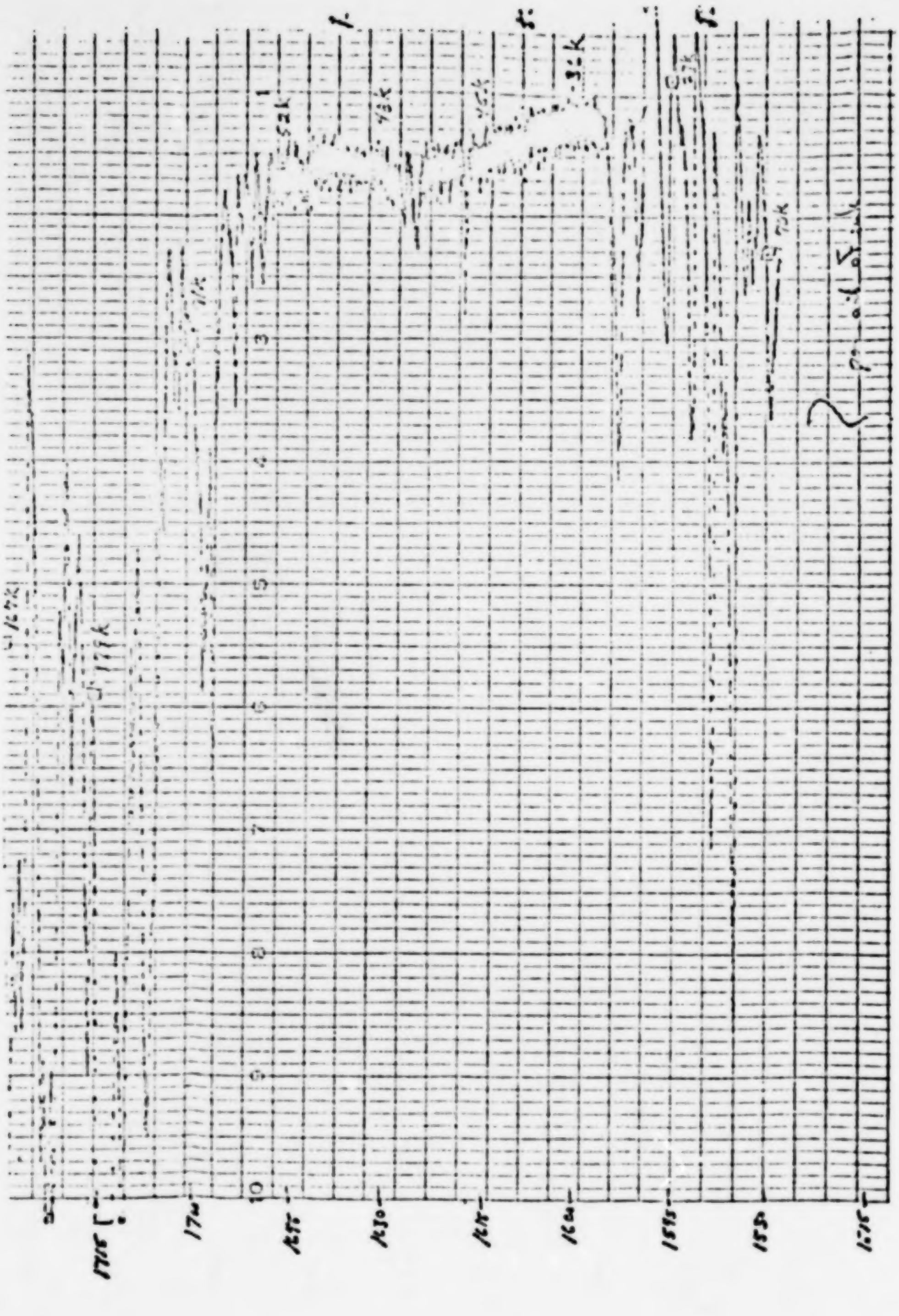

Figure 139 (continued). CNC chart recording for run 28

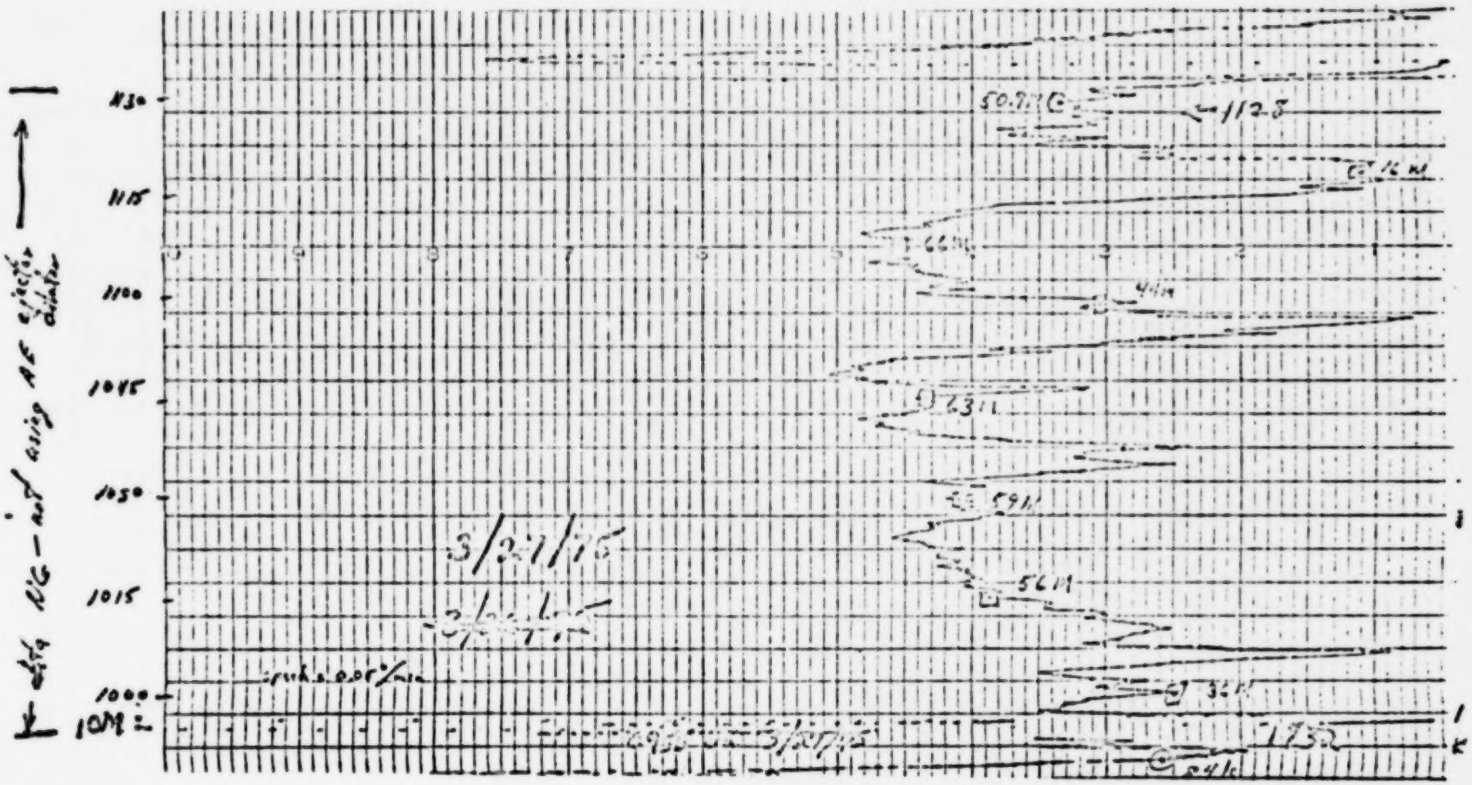

Figure 140. CNC chart recording for run 29

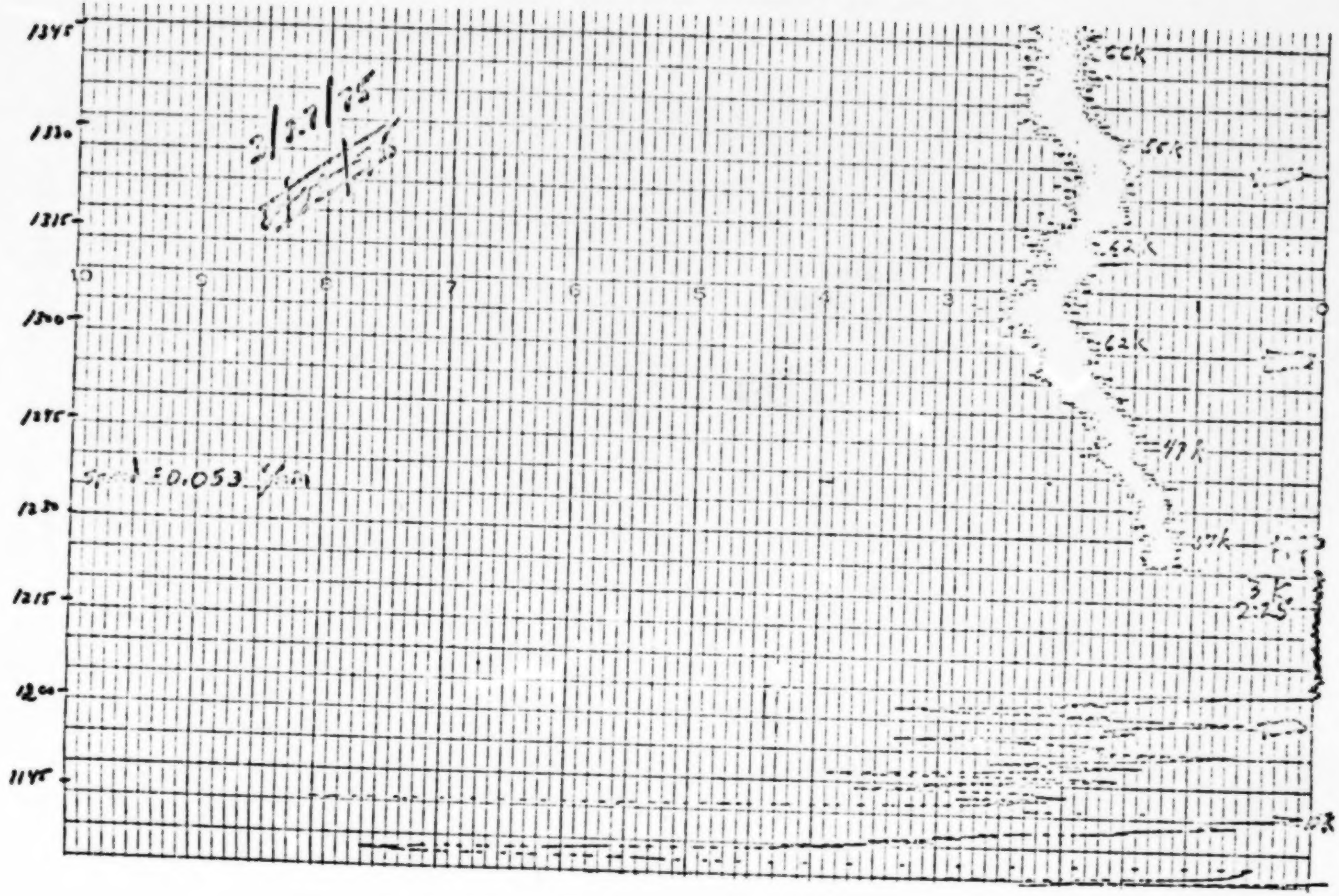

Figure 140 (continued). CNC chart recording for run 29

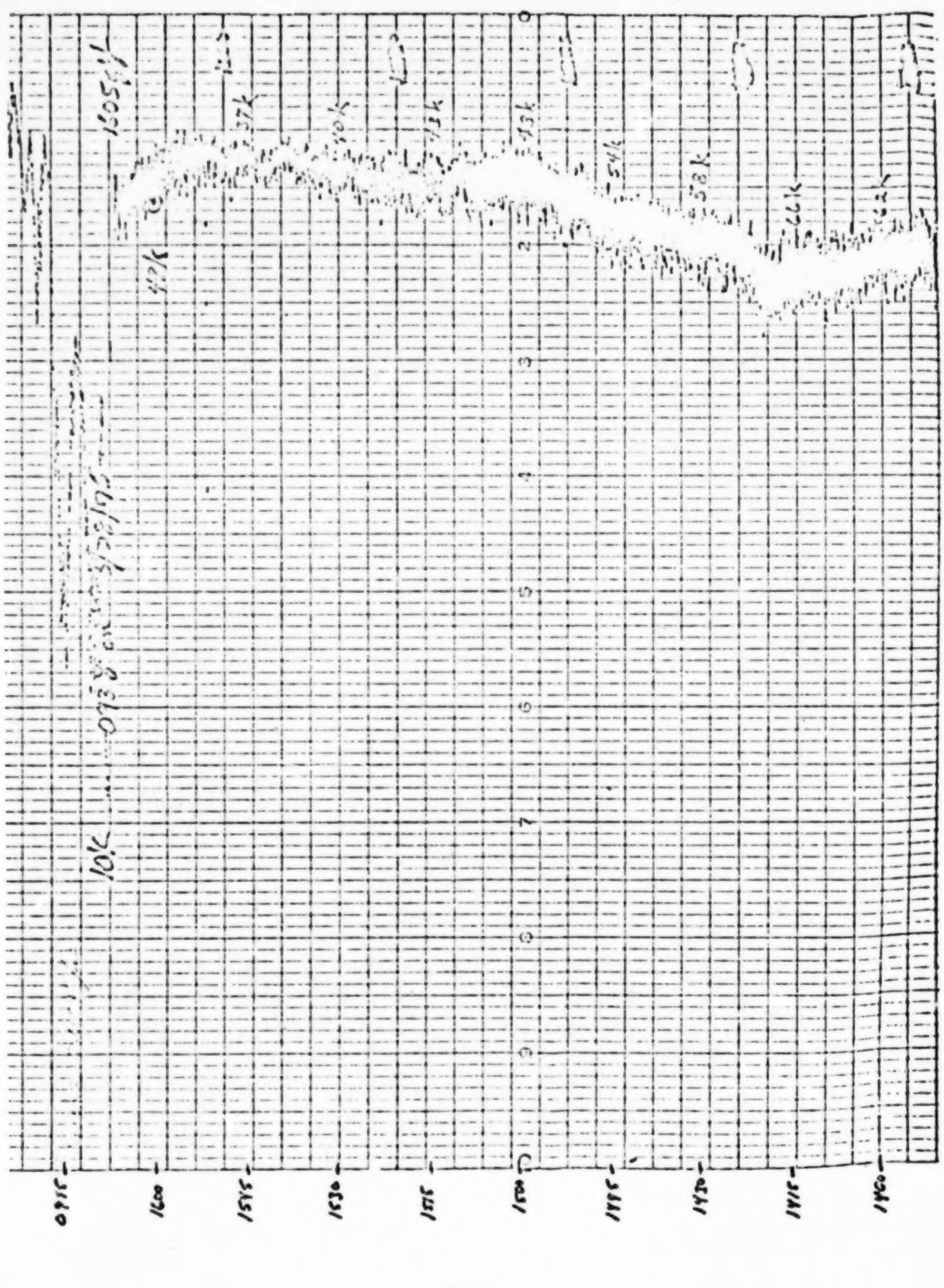

Figure 140 (continued). CNC chart recording for run 29

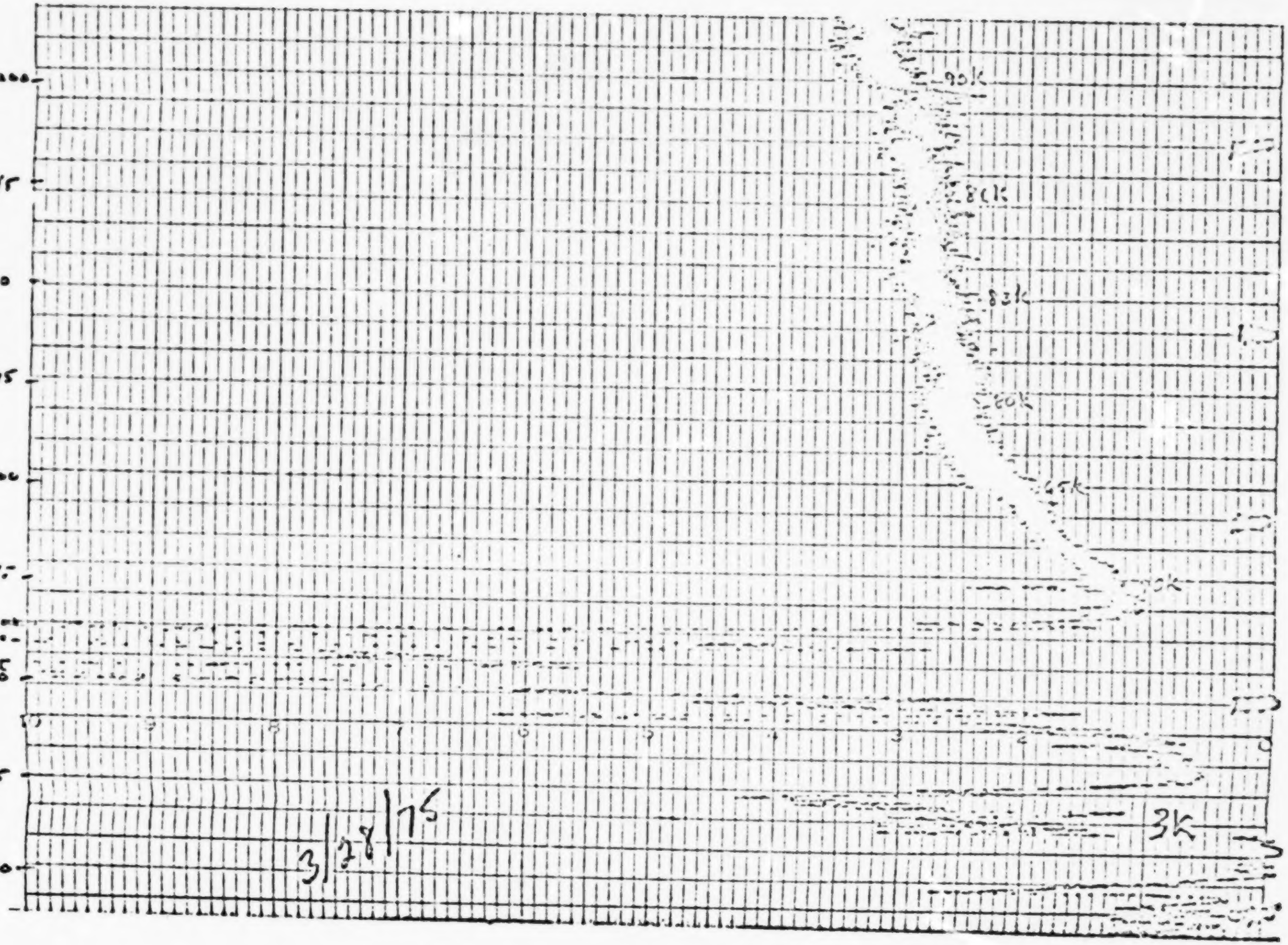

Figure 141. CNC chart recording for run 30

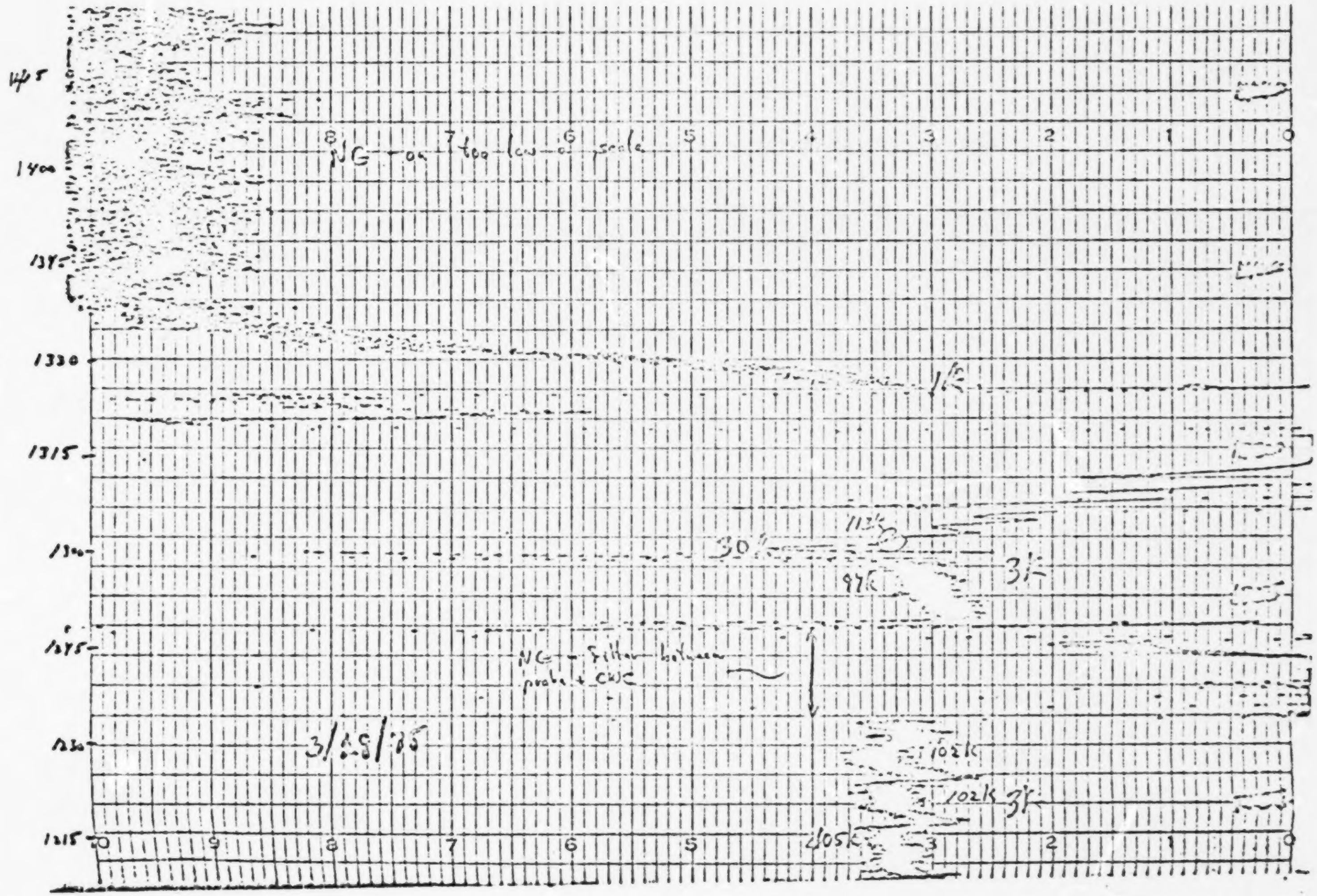

Figure 141 (continued). CNC chart recording for run 30

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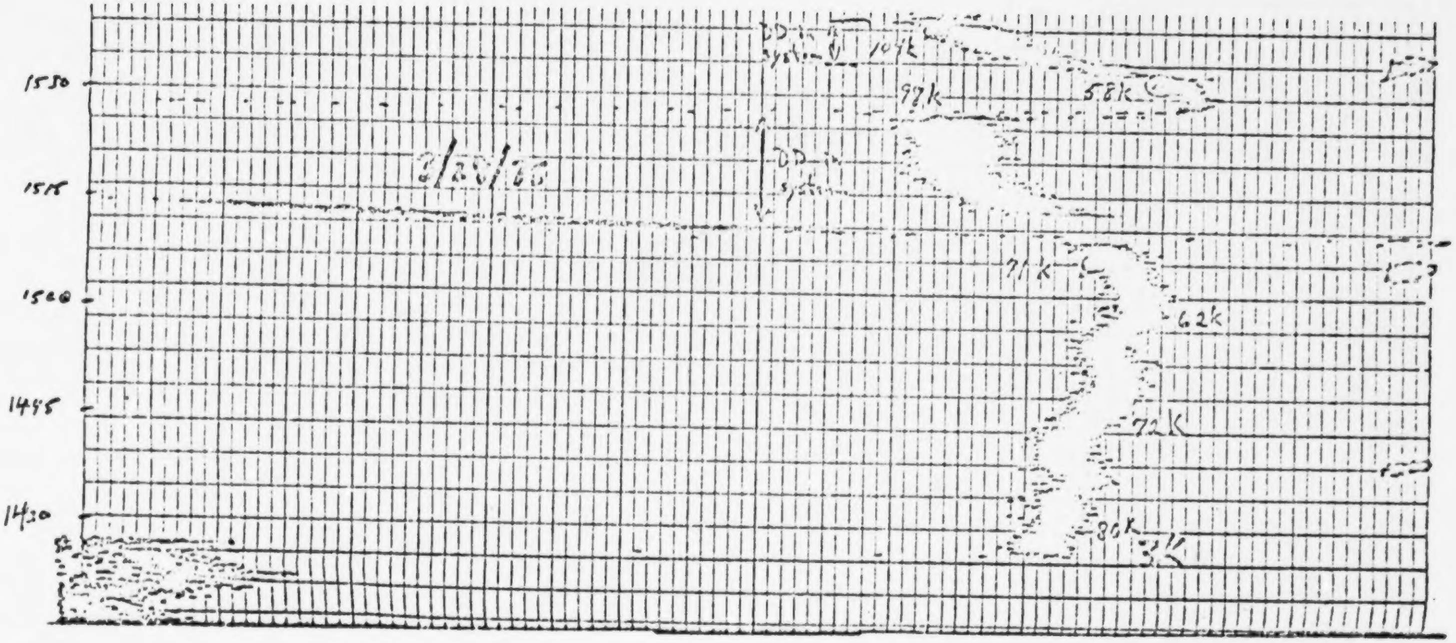

Figure 141 (continued). CNC chart recording for run 30

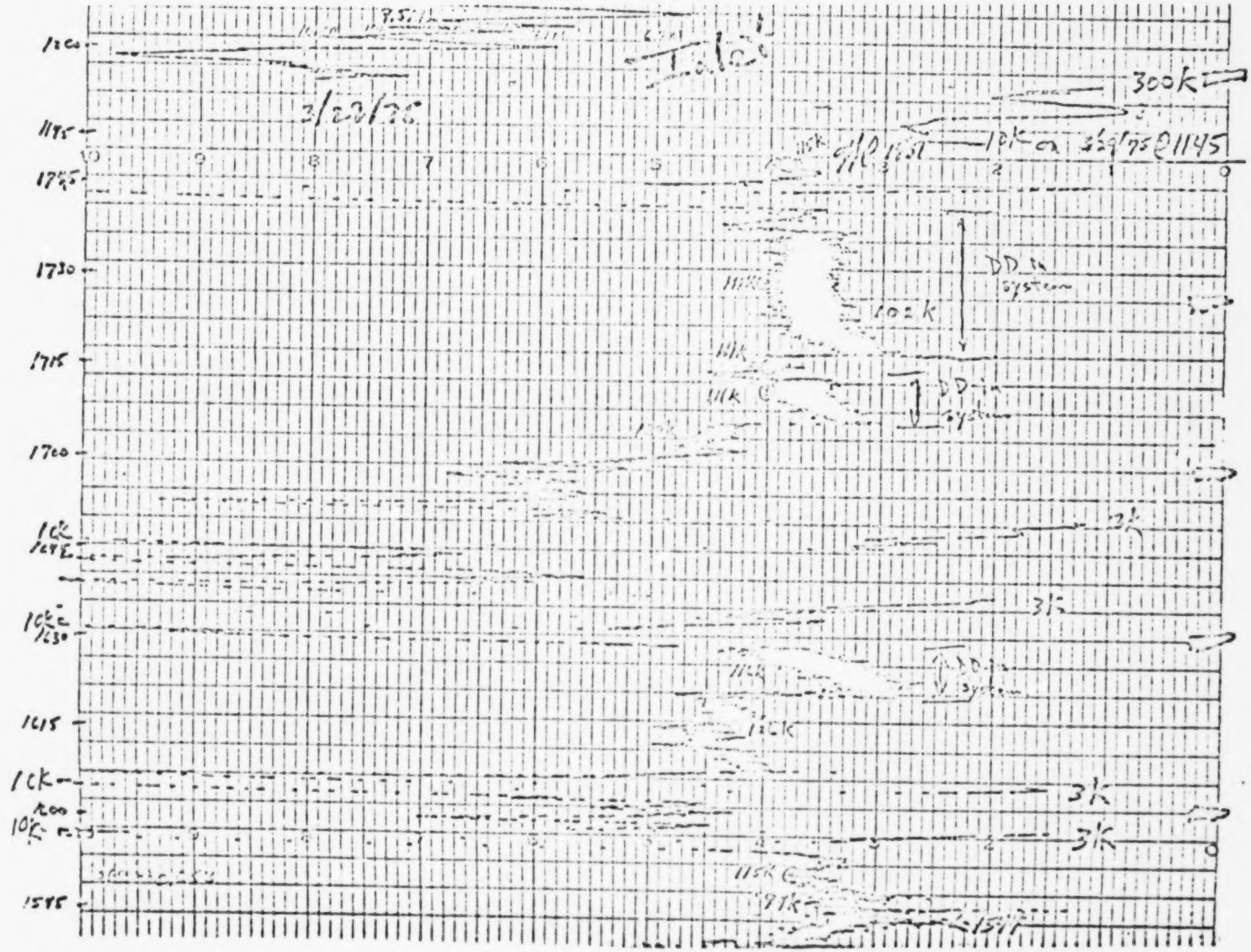

Figure 142. CNC chart recording for run 31

APPENDIX F

COAL ANALYSIS

Table 26. SUNBURY COAL ANALYSIS

Run #	Fuel	As received						Dry basis				
		Total moisture %	Volatile matter %	Fixed carbon %	Ash %	Btu per pound	Sulfur %	Volatile matter %	Fixed carbon %	Ash %	Btu per pound	Sulfur %
1	Pulv. boiler feed	2.9	7.7	71.4	18.0	11,707	2.0	7.9	73.6	18.5	12,050	2.1
	Pet. coke	5.4	8.8	81.9	3.9	13,563	4.6	9.3	86.6	4.1	14,342	4.9
	Anth. silt	18.6	6.9	52.8	21.7	8,698	0.6	8.5	64.8	26.7	10,685	0.7
	Anth. no. 5 buck	a										
2	Pulv. boiler feed	3.1	9.4	68.3	19.2	11,657	2.2	9.7	70.5	19.8	12,032	2.3
	Pet. coke	7.2	11.3	80.6	0.9	14,197	4.7	12.2	86.8	1.0	15,292	5.1
	Anth. silt	15.3	6.1	53.6	25.0	8,570	0.6	7.2	63.3	29.5	10,117	0.7
	Anth. no. 5 buck											
3	Pulv. boiler feed	4.2	8.3	64.9	22.6	10,865	1.6	8.7	67.7	23.6	11,337	1.7
	Pet. coke	4.9	12.5	82.4	0.2	14,759	4.9	13.1	86.7	0.2	15,515	5.2
	Anth. silt	16.2	6.4	51.2	26.2	8,241	0.6	7.6	61.1	31.3	9,832	0.7
	Anth. no. 5 buck											
4	Pulv. boiler feed	3.1	8.3	64.3	24.3	10,725	1.6	8.6	66.3	25.1	11,063	1.7
	Pet. coke	4.3	12.4	82.5	0.8	14,731	4.7	13.0	86.2	0.8	15,397	4.9
	Anth. silt	17.6	7.1	50.8	24.5	8,296	0.7	8.6	61.7	29.7	10,073	0.8
	Anth. no. 5 buck											
5	Pulv. boiler feed	3.0	7.5	66.6	22.9	10,953	1.6	7.7	68.7	23.6	11,293	1.6
	Pet. coke	4.6	11.7	83.5	0.2	14,720	4.6	12.3	87.5	0.2	15,434	4.8
	Anth. silt	17.4	6.3	51.9	24.4	8,427	0.6	7.6	62.9	29.5	10,203	0.7
	Anth. no. 5 buck											
6	Pulv. boiler feed	2.6	8.5	68.4	20.5	11,443	2.1	8.7	70.2	21.1	11,753	2.2
	Pet. coke	3.8	11.7	84.3	0.2	14,874	4.9	12.2	87.6	0.2	15,466	5.1
	Anth. silt	19.5	6.8	50.1	23.6	8,187	0.6	8.5	62.2	29.3	10,176	0.7
	Anth. no. 5 buck											
7	Pulv. boiler feed	3.4	7.7	58.4	30.5	9,710	1.7	8.0	60.4	31.6	10,049	1.8
	Pet. coke	7.2	12.3	80.4	0.1	14,407	4.8	13.3	86.6	0.1	15,525	5.2
	Anth. silt	19.5	6.0	48.9	25.6	7,870	0.6	7.5	60.7	31.8	9,778	0.7
	Anth. no. 5 buck											
8	Pulv. boiler feed	2.9	7.9	60.6	28.6	10,084	1.5	8.1	62.4	29.5	10,387	1.5
	Pet. coke	4.7	13.0	82.0	0.3	14,748	4.7	13.6	86.1	0.3	15,477	4.9
	Anth. silt	14.4	5.3	38.1	42.2	5,831	0.3	6.2	44.5	49.3	6,814	0.4
	Anth. no. 5 buck											
9	Pulv. boiler feed	3.2	8.6	66.3	21.9	11,135	2.1	8.9	68.5	22.6	11,500	2.2
	Pet. coke	7.3	11.1	81.1	0.5	14,311	4.5	12.0	87.5	0.5	15,432	4.9
	Anth. silt	17.0	6.2	49.2	27.6	7,932	0.6	7.5	59.3	33.2	9,553	0.7
	Anth. no. 5 buck	12.3	7.8	62.4	17.5	10,399	0.9	8.9	71.2	19.9	11,854	1.0
10	Pulv. boiler feed	3.0	7.9	66.8	22.3	10,914	1.4	8.1	68.9	23.0	11,249	1.4
	Pet. coke	7.4	10.8	75.8	6.0	13,101	4.0	11.7	81.8	6.5	14,140	4.3
	Anth. silt	17.8	6.3	50.4	25.5	8,065	0.6	7.7	61.3	31.0	9,809	0.7
	Anth. no. 5 buck	10.6	7.8	62.9	18.7	10,382	0.6	8.7	70.4	20.9	11,614	0.7

[a] Blanks indicate that no sample was collected.

Table 26 (continued). SUNBURY COAL ANALYSIS

		As received						Dry basis				
Run #	Fuel	Total moisture %	Volatile matter %	Fixed carbon %	Ash %	Btu per pound	Sulfur %	Volatile matter %	Fixed carbon %	Ash %	Btu per pound	Sulfur %
11	Pulv. boiler feed	2.5	8.3	70.0	19.2	11,678	2.1	8.5	71.8	19.7	11,975	2.2
	Pet. coke	7.9	10.7	80.0	1.4	14,093	4.3	11.6	86.9	1.5	15,308	4.7
	Anth. silt											
	Anth. no. 5 buck	12.1	7.4	63.7	16.8	10,500	0.6	8.4	72.5	19.1	11,942	0.7
12	Pulv. boiler feed	2.1	9.5	72.7	15.7	12,403	3.1	9.7	74.3	16.0	12,666	3.2
	Pet. coke	9.8	10.5	79.1	0.6	13,899	0.6	11.6	87.7	0.7	15,414	0.7
	Anth. silt	16.6	6.8	47.6	29.0	7,782	0.5	8.1	57.1	34.8	9,327	0.6
	Anth. no. 5 buck	11.5	7.1	63.1	18.3	10,327	0.5	8.0	71.3	20.7	11,671	0.6
13	Pulv. boiler feed	2.6	8.1	71.0	18.3	11,716	1.6	8.3	72.9	18.8	12,023	1.6
	Pet. coke	7.1	10.4	81.8	0.7	14,266	4.7	11.2	88.0	0.8	15,356	5.1
	Anth. silt	17.5	6.1	45.4	31.0	7,261	0.4	7.4	55.0	37.6	8,800	0.5
	Anth. no. 5 buck	11.4	6.6	65.8	16.2	10,662	0.5	7.5	74.2	18.3	12,035	0.6
14	Pulv. boiler feed	1.7	8.5	71.4	18.4	11,909	1.7	8.6	72.7	18.7	12,117	1.7
	Pet. coke	8.8	10.3	80.7	0.2	14,063	4.6	11.3	88.5	0.2	15,426	5.1
	Anth. silt	18.4	6.0	43.8	31.8	6,983	0.3	7.4	53.7	38.9	8,552	0.4
	Anth. no. 5 buck	14.1	6.0	63.4	16.5	10,237	0.5	7.0	73.8	19.2	11,916	0.6
15	Pulv. boiler feed	3.0	7.8	67.7	21.5	11,116	1.3	8.0	69.8	22.2	11,454	1.3
	Pet. coke	6.8	11.8	81.3	0.1	14,431	4.6	12.7	87.2	0.1	15,490	4.9
	Anth. silt	19.4	5.3	49.6	25.7	7,755	0.4	6.6	61.5	31.9	9,618	0.5
	Anth. no. 5 buck	14.5	6.7	60.5	18.3	9,841	0.6	7.8	70.9	21.3	11,507	0.7
16	Pulv. boiler feed	2.7	7.5	69.7	20.1	11,440	1.2	7.7	71.7	20.6	11,752	1.2
	Pet. coke	7.0	8.5	84.3	0.2	14,456	3.9	9.1	90.7	0.2	15,539	4.2
	Anth. silt	18.5	5.9	49.3	26.3	7,831	0.4	7.2	60.5	32.3	9,611	0.5
	Anth. no. 5 buck	15.2	6.4	60.6	17.8	9,781	0.5	7.5	71.5	21.0	11,537	0.6
17	Pulv. boiler feed	3.2	7.8	66.3	22.7	10,956	1.5	8.1	68.4	23.5	11,319	1.6
	Pet. coke	8.3	11.0	80.6	0.1	14,271	3.9	12.0	87.9	0.1	15,554	4.3
	Anth. silt	19.1	6.2	47.6	27.1	7,587	0.5	7.7	58.8	33.5	9,376	0.6
	Anth. no. 5 buck											
18	Pulv. boiler feed	2.4	8.8	70.3	18.5	11,802	1.5	9.0	72.0	19.0	12,091	1.5
	Pet. coke	10.3	8.7	79.4	1.6	13,570	3.5	9.7	88.5	1.8	15,124	3.9
	Anth. silt	19.3	6.2	51.5	23.0	8,310	0.5	7.7	63.8	28.5	10,299	0.6
	Anth. no. 5 buck	12.6	7.4	68.4	11.6	11,382	1.5	8.5	78.2	13.3	13,022	1.7
19	Pulv. boiler feed	2.8	8.4	67.8	21.0	11,374	1.5	8.6	69.8	21.6	11,469	1.5
	Pet. coke	6.2	12.8	80.8	0.2	14,685	4.0	13.6	86.2	0.2	15,647	4.3
	Anth. silt	18.1	5.8	50.8	25.3	8,066	0.4	7.1	62.0	30.9	9,851	0.5
	Anth. no. 5 buck	16.5	5.3	57.2	21.0	8,978	0.4	6.3	68.6	25.1	10,748	0.5
20	Pulv. boiler feed	2.6	7.5	68.3	21.6	11,246	1.2	7.7	70.1	22.2	11,545	1.2
	Pet. coke	7.6	12.0	79.8	0.6	14,346	3.9	13.0	86.3	0.7	15,521	4.2
	Anth. silt	19.0	5.9	51.2	23.9	8,208	0.4	7.3	63.2	29.5	10,139	0.5
	Anth. no. 5 buck	12.6	6.2	62.9	18.3	10,076	0.5	7.1	72.0	20.9	11,534	0.6
21	Pulv. boiler feed	1.8	8.0	68.9	21.3	11,408	1.4	8.1	70.2	21.7	11,614	1.4
	Pet. coke	7.7	11.2	80.9	0.2	14,382	4.2	12.1	87.7	0.2	15,583	4.6
	Anth. silt	18.6	7.1	55.7	18.6	9,252	1.0	8.7	68.5	22.8	11,361	1.2
	Anth. no. 5 buck	15.7	5.7	64.1	14.5	10,328	0.4	6.8	76.0	17.2	12,247	0.5

Table 26 (continued). SUNBURY COAL ANALYSIS

Run #	Fuel	As received						Dry basis				
		Total moisture %	Volatile matter %	Fixed carbon %	Ash %	Btu per pound	Sulfur %	Volatile matter %	Fixed carbon %	Ash %	Btu per pound	Sulfur %
22	Pulv. boiler feed	2.3	7.6	69.9	20.2	11,454	2.0	7.8	71.5	20.7	11,717	2.1
	Pet. coke	8.1	9.9	79.3	2.7	13,616	5.0	10.8	86.3	2.9	14,811	5.4
	Anth. silt	14.8	6.4	54.1	24.7	8,692	0.4	7.5	63.5	29.0	10,203	0.5
	Anth. no. 5 buck											
23	Pulv. boiler feed	3.5	8.2	66.8	21.5	11,117	1.7	8.5	69.2	22.3	11,519	1.8
	Pet. coke	9.0	10.6	77.9	2.5	13,519	4.5	11.6	85.6	2.8	14,848	4.9
	Anth. silt	15.1	5.8	52.5	26.6	8,310	0.5	6.8	61.9	31.3	9,787	0.6
	Anth. no. 5 buck											
24	Pulv. boiler feed	3.6	8.0	66.6	21.8	10,989	1.7	8.3	69.1	22.6	11,401	1.8
	Pet. coke	8.4	11.5	79.6	0.5	14,003	5.1	12.6	86.8	0.6	15,287	5.6
	Anth. silt	19.3	5.9	47.0	27.8	7,510	0.4	7.3	58.3	34.4	9,306	0.5
	Anth. no. 5 buck	13.0	6.7	62.1	18.2	10,121	0.6	7.7	71.4	20.9	11,635	0.7
25	Pulv. boiler feed	4.1	8.4	67.7	19.8	11,263	2.3	8.8	70.6	20.6	11,741	2.4
	Pet. coke	5.3	12.3	81.9	0.5	14,553	5.5	13.0	86.5	0.5	15,367	5.8
	Anth. silt	19.9	5.0	50.5	24.6	7,786	0.3	6.2	63.1	30.7	9,715	0.4
	Anth. no. 5 buck											
26	Pulv. boiler feed	3.5	7.5	66.6	22.4	10,838	1.5	7.8	69.0	23.2	12,258	1.6
	Pet. coke	7.8	12.0	79.3	0.9	14,114	5.4	13.0	86.0	1.0	15,308	5.9
	Anth. silt	18.0	5.8	51.8	24.4	8,071	0.4	7.1	63.1	29.8	9,847	0.5
	Anth. no. 5 buck	12.9	6.2	66.2	14.7	10,674	0.5	7.1	76.0	16.9	12,256	0.6
27	Pulv. boiler feed	2.7	9.3	70.2	17.8	11,817	2.0	9.6	72.1	18.3	12,143	2.1
	Pet. coke	4.3	11.9	83.5	0.3	14,767	5.2	12.4	87.3	0.3	15,427	5.4
	Anth. silt	16.0	6.0	52.3	25.7	8,230	0.4	7.1	62.3	30.6	9,795	0.5
	Anth. no. 5 buck	14.5	7.3	60.3	17.9	9,910	0.7	8.5	70.6	20.9	11,590	0.8
28	Pulv. boiler feed	3.2	8.2	68.2	20.4	11,255	2.0	8.5	70.4	21.1	11,626	2.1
	Pet. coke	6.8	11.4	81.7	0.1	14,371	5.5	12.2	87.7	0.1	15,422	5.9
	Anth. silt	18.6	5.5	51.7	24.2	8,108	0.4	6.8	63.5	29.7	9,963	0.5
	Anth. no. 5 buck	15.9	7.7	58.9	17.5	9,744	0.8	9.2	70.0	20.8	11,590	1.0
29	Pulv. boiler feed	3.6	7.6	65.9	22.9	10,784	1.5	7.9	68.3	23.8	11,186	1.6
	Pet. coke	6.1	10.5	82.0	1.4	14,207	4.8	11.2	87.3	1.5	15,126	5.1
	Anth. silt	17.5	5.3	53.0	24.2	8,283	0.4	6.4	64.3	29.3	10,045	0.5
	Anth. no. 5 buck	11.6	7.2	65.3	15.9	10,572	0.7	8.2	73.8	18.0	11,963	0.8
30	Pulv. boiler feed	2.7	7.7	67.1	22.5	11,003	1.5	7.9	69.0	23.1	11,303	1.5
	Pet. coke	8.3	11.0	80.0	0.7	14,065	4.9	12.0	87.2	0.8	15,334	5.3
	Anth. silt	15.9	5.8	54.4	23.9	8,563	0.4	6.9	64.7	28.4	10,181	0.5
	Anth. no. 5 buck											
31	Pulv. boiler feed	3.3	8.0	67.4	21.3	11,141	1.9	8.3	69.7	22.0	11,521	2.0
	Pet. coke	7.3	10.7	81.0	1.0	14,162	4.7	11.5	87.4	1.1	15,275	5.1
	Anth. silt	18.2	5.7	53.6	22.5	8,569	0.4	7.0	65.5	27.5	10,470	0.5
	Anth. no. 5 buck	19.1	5.6	52.9	22.4	8,452	0.4	6.9	65.4	27.7	10,442	0.5

APPENDIX G

BAGHOUSE PRESSURE DROP CHART RECORDING

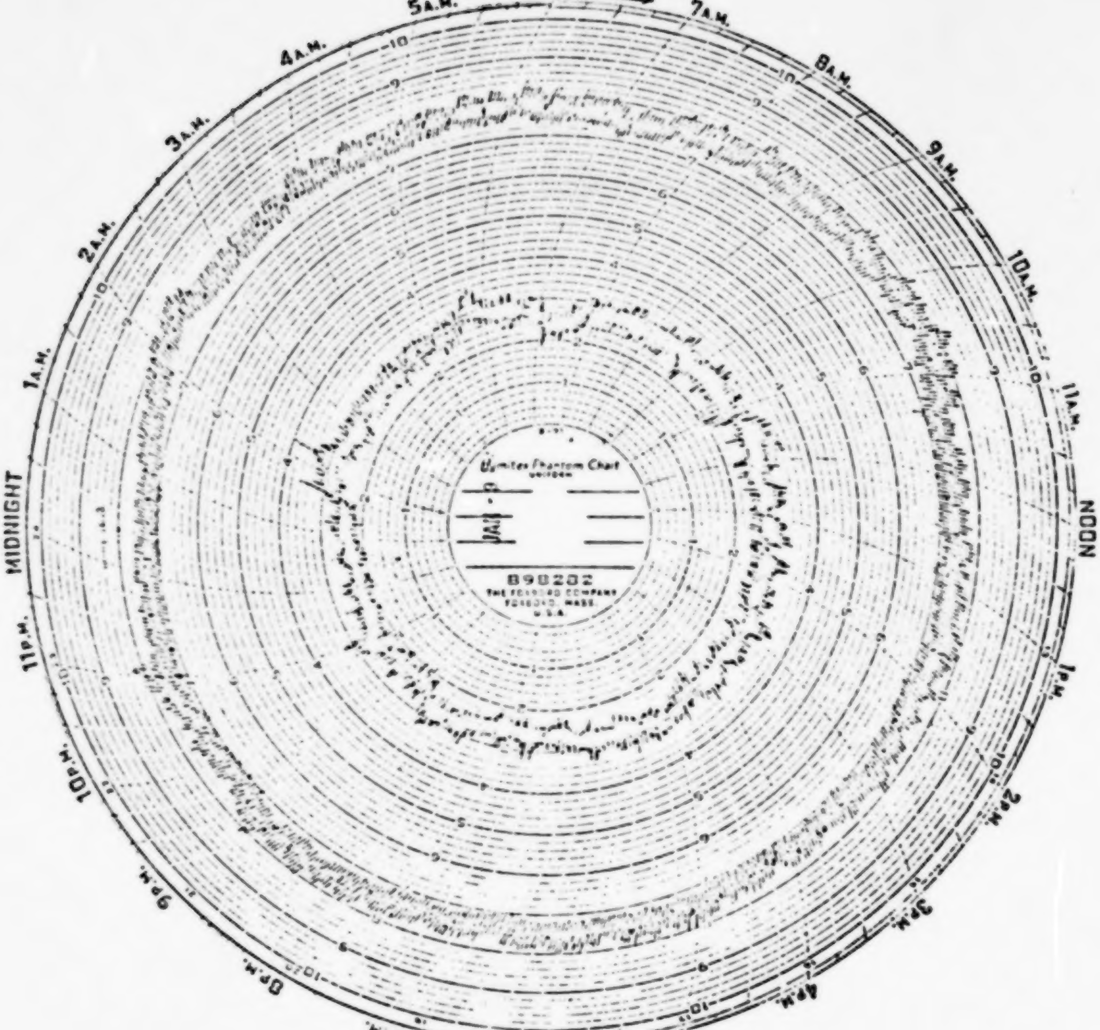

Figure 143. Baghouse pressure drop chart recording for run 2

APPENDIX H

GASEOUS MEASUREMENTS

Table 27. GASEOUS MEASUREMENTS

Time	O_2, %	SO_2, ppm	CO_2, %
Run No. 1			
1620	7.40	1633	13.3
1625	7.38	1633	13.5
1630	7.88	1666	13.3
1635	8.38	1666	12.3
1640	8.00	1650	12.9
1645	7.38	1650	13.5
1650	7.35	1650	13.7
1655	7.50	1650	13.4
1700	8.25	1633	13.1
1705	7.50	1633	13.5
1710	8.12	1633	12.9
1715	9.00	1633	12.9
1720	8.50	1616	13.4
1725	7.38	1616	13.4
1730	8.12	1616	12.2
1735	8.25	1616	12.9
1740	8.88	1600	12.1
1745	8.00	1600	12.8
1750	8.12	1600	12.9
1755	8.12	1600	12.9
1800	8.12	1600	12.9
1805 - 1910	no data		
1915	8.25	1600	13.4
1920	7.88	1567	13.5
1925	8.25	1533	12.6
1930	8.25	1517	13.2
1935	8.00	1450	13.3
1940	8.00	1483	13.2
1945	8.75	1467	13.4
1950	8.00	1467	13.3
1955	8.12	1450	13.2
2000	8.38	1433	12.9
2005	7.88	1450	13.3
Run No. 8			
1955	10.12	no readings	12.2
2000	10.35		11.1
2005	9.70		11.8
2010	9.65		11.6
2015	10.35		11.5

Table 27 (continued). GASEOUS MEASUREMENTS

Time	O_2, %	SO_2, ppm	CO_2, %
Run No. 24			
1418	8.5	1330	10.3
1521	9.5	1230	9.1
1623	7.3	1490	11.0
1727	8.0	1240	10.8
Run No. 25			
1118	8.9	1650	10.8
1221	7.7	1360	11.5
1324	8.4	1220	11.0
1410	7.6	1150	11.3
1514	8.4	1360	10.9
1617	8.5	1420	10.2
Run No. 26			
1200	8.8	1915	12.4
1303	8.2	1890	12.4
1405	8.6	1790	12.0
1508	10.0	1870	11.6
Run No. 27			
1005	8.9	1890	11.8
1107	9.2	1790	11.7
1210	9.5	1670	11.8
1313	10	1670	10.8
1415	8.8	1790	12.0
1517	8.5	1730	12.7
Run No. 28			
1030	10.0	1830	11.1
1132	9.0	1700	11.9
1235	9.0	1600	12.2
1337	9.2	1500	11.9
1440	9.2	1510	12.0
1543	8.8	1450	11.6

Table 27 (continued). GASEOUS MEASUREMENTS

Time	O_2, %	SO_2, ppm	CO_2, %
Run No. 29			
1027	9.8	1450	11.6
1129	9.7	1380	11.8
1232	9.2	1300	12.0
1335	10.2	1400	11.1
1437	9.0	1370	11.8
Run No. 30			
1002	9.5	no reading	12.4
1105	10.8	1370	11.1
1208	9.8	1320	12.0
1311	9.7	1290	12.4
1415	9.4	1230	12.2
1518	9.8	1230	12.0
Run No. 31			
0811	9.8	1370	11.6
0915	10.2	1370	10.8
1018	10.6	1175	11.1
1121	10.0	1210	11.1